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containing original contributions only, appears bi-monthly, January, March, May, July, September, and November, the six numbers comprising a volume of about 540 pages.

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THE EFFICACY OF INTENSIFIED REWARD AND OF INTENSIFIED PUNISHMENT[1]

BY IRVING LORGE

Teachers College, Columbia University

WITH THE ASSISTANCE OF THE STAFF OF THE DIVISION OF PSYCHOLOGY OF THE INSTITUTE OF EDUCATIONAL RESEARCH

Rewards and, presumably, punishments are important means used by society to reach ends in the learning of information, the acquisition of skills, and the development of attitudes. So important are these means, that any experiment designed to determine the efficacy of rewards and punishments needs no imposing array of argument to justify the effort. The results, if reliable, are their own justification.

Thorndike ('32) has demonstrated the potency of an after-effect of a connection to change learning. These after-effects in the form of symbolic statement *Right* for correct responses, and of *Wrong* for incorrect responses do affect the course of learning. The efficiency of a *Right* differs materially from that of a *Wrong*. Thorndike finds that

> "By any reasonable estimate of the expectation by chance, it will still be true that the learning occurred only by strengthening of the announcement of *Right*, the wrong response doing more harm by occurring than good by being punished by *Wrong*" (p. 291).

So important is this generalization concerning the differential effect of a reward and of a punishment that additional experimentation is needed if only to add to the mass of evidence

[1] This investigation is made possible by a grant from The Carnegie Corporation.

already accumulated. If "annoying after-effects are not dynamically the opposites of satisfiers, but more specialized in their action" (p. 313), we must assay annoyers and satisfiers for their bearing upon teaching, business, penology, and the kindred fields of human endeavor where improvement from some status is sought.

The differential effect of rewards and punishments, if substantiated, must result in changes in the technics in teaching of individuals, in the disciplining of malefactors, in the securing of efficiency in industry, and in the development of ideals in society.

Thorndike has arrived at his results through the use of symbolic rewards and punishments. The results are important for life in general, since most of the annoyers and satisfiers that operate in civilized communities are symbolic. In many instances, however, society and individuals have sought to intensify symbolic incentives to action, in the belief that if little palliates, much cures.

These experiments, though of the same general nature as Thorndike's in that the multiple choice form is used, differ in at least four particulars:

1. A variety of materials differing in meaningfulness is used.
2. An intensified reward, and an intensified punishment is employed.
3. The initial chance of rightness or wrongness is equalized.
4. The after-effects are compared for stimuli having similar histories.

Accumulation of results from diverse materials will demonstrate the differential after-effect of a punishment and of a reward. Five types of material, all of the multiple choice form, are used. One type is concerned with vocabulary learning of real words; another, with the connecting of nonsense words with real words; a third, with the connecting of a nonsense symbol with a thought-of number; a fourth, with connecting the position of a particular nonsense syllable with the whole line of four such symbols; and a fifth, with connecting the position of a particular two-lettered syllable with

the whole line of four such di-letters. Samples of the materials used are shown in Figs. 1 to 5.

21. arder	help....buckle....burn....hoard....supply	 21
22. argado	envy....hope....speech....howl....trick	 22
23. asa	fair....handle....loving....rebel....elbow	 23
24. astaco	peach....hardness....meteor....auburn....lobster	 24
25. asueto	vacation....castle....river....custom....readiness	 25

FIG. 1. Spanish word to meaningful English word.

aptitude degeneracy hilarity survival
clutter electrify reek swear
deer fauna jawbone kingfisher
aground fetid hoarse peevish
coconut dewberry quince shaddock

FIG. 2. Nonsense word to meaningful English word.

FIG. 3. Nonsense symbol to thought-of number.

FIG. 4. Position of a symbol to the whole line.

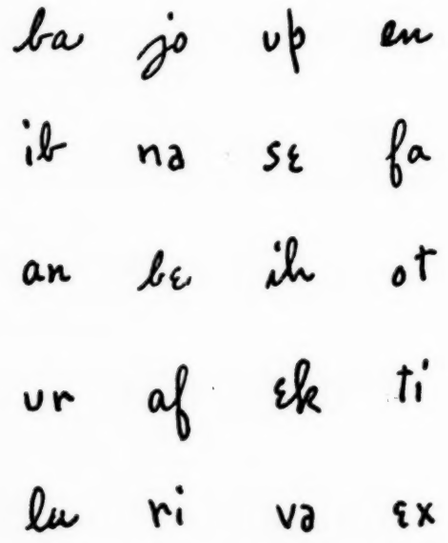

FIG. 5. Position of a di-letter to the whole line.

To intensify the effect of the symbolic *Right*, a slight money reward was added to the satisfaction of correctness. To intensify the effect of the symbolic *Wrong*, an electric shock was added to the annoyance of wrongness. Intensification of after-effects should cause the right response to be repeated more than is likely by chance. If a wrong response does more harm by occurring than punishment of it can offset, then this experiment with intensified punishment should give a crucial check on Thorndike's findings.

Equalization of chance at initial trial to avoid the con-

sequence of overweighting failure or success was secured by reducing the number of choices from five to four, and by arbitrarily having two rights instead of one. In any line of nonsense words to meaningful English words, a subject has an equal chance of getting a right or a wrong response in trial one. The limiting set-up of two choices, with one right and one wrong, would have given the same equalization of initial chance. Such a set-up suffers, however, from the difficulty that a statement of a wrong for one response is tantamount to saying the other is right. These experiments in general, then, have possibilities of two rights and of two wrongs in trial one.

Some one hundred subjects participated in these experiments. In general, we take the common-sense viewpoint that if the average status of the subjects who participated in an experiment is, at trial five, an improvement over the initial status, learning has taken place; and that if no such improvement has occurred, no learning has taken place. (Any other reasonable criterion by which learning is distinguished would be satisfactory.) Therefore, in any experiment, if the entire group on the average showed no improvement, the records of the group were not used for reward-punishment comparison, although such records may be very useful for other problems.

The records of each subject were scored in terms of right and wrong, and since there were two rights and two wrongs for each stimulus, the responses were scored as either C_1 or C_2 or as X_1 or X_2 where

C_1 for every stimulus represents the right response first in order on the key, and
C_2 for every stimulus, the right response second in order;
X_1 for every stimulus, the wrong response first in order on the key, and
X_2 for every stimulus, the wrong response second in order.

Table 1 gives an example of how each subject's responses were scored in terms of the C_1, C_2, X_1, X_2 symbolism.

For every experiment there is a record such as Table 1, for

TABLE 1

THE RESPONSES OF SUBJECT LE IN EXPERIMENT ONE WITH THE KEY AND THE TRANSLITERATION OF THE RESPONSES IN TERMS OF THE C_1 C_2 X_1 X_2 SYMBOLISM

Key*	Order of Presentation of Symbols in Trial 1	Actual Responses at Trial					Responses Transliterated into C_1 C_2 X_1 X_2 Symbolism at Trial				
		1	2	3	4	5	1	2	3	4	5
3, 4	1	3	3	3	3	3	C_1	C_1	C_1	C_1	C_1
1, 4	2	2	4	4	4	4	X_1	C_2	C_2	C_2	C_2
1, 3	3	3	2	3	3	3	C_2	X_1	C_2	C_2	C_2
1, 4	4	2	3	4	3	4	X_1	X_2	C_2	X_2	C_2
2, 3	5	3	2	2	2	2	C_2	C_1	C_1	C_1	C_1
1, 2	6	4	4	4	3	2	X_2	X_2	X_2	X_1	C_1
1, 3	7	1	1	1	1	2	C_1	C_1	C_1	C_1	X_1
3, 4	8	1	1	2	3	3	X_1	X_1	X_2	C_1	C_1
2, 3	9	3	1	1	3	3	C_2	X_1	X_1	C_2	C_2
2, 4	10	4	3	3	4	2	C_2	X_2	X_2	C_2	C_1
3, 4	11	2	3	3	3	3	X_2	C_1	C_1	C_1	C_1
2, 3	12	4	3	4	3	4	X_2	C_2	X_2	C_2	X_2
1, 2	13	2	2	2	2	2	C_2	C_2	C_2	C_2	C_2
1, 3	14	4	3	3	3	3	X_2	C_2	C_2	C_2	C_2
1, 2	15	3	2	2	2	2	X_1	C_2	C_2	C_2	C_2
1, 4	16	4	4	4	4	4	C_2	C_2	C_2	C_2	C_2
2, 4	17	3	3	4	3	3	X_2	X_2	C_2	X_2	X_2
2, 4	18	4	3	3	1	3	C_2	X_2	X_2	X_1	X_2
2, 3	19	4	4	4	2	2	X_2	X_2	X_2	C_1	C_1
1, 4	20	1	2	2	1	1	C_1	X_1	X_1	C_1	C_1

* If the subject responded with either of the two numbers of the key, he was told *Right* and given a token worth one tenth of a cent. If he responded with either of the two numbers not on the key, he was told *Wrong* and given an electric shock.

each subject who participated in that experiment. Table 2 summarizes and analyzes the ten such records of Experiment 1.

The analysis of the records in general will be illustrated by the analysis of the records of the ten subjects reported in Table 2. This illustration is interpolated primarily to allow the reader to follow the argument with actual data.

The C_1C_1 row shows by individuals the number of cases in which a C_1 response in trial 1 was followed by C_1 in trial 2. The C_1-other row shows the number of times that a C_1 response in trial 1 was followed by a different response in trial 2. Similarly the C_2C_2 row gives the number of cases in which a C_2 response in trial 1 was followed by C_2 in trial 2;

and C_2-other indicates the number of times that a C_2 response in trial 1 was followed by some other response in trial 2. In like manner, the table shows how many X_1 responses in trial 1 were X_1 in trial 2, or were followed by any other response in trial 2. It also shows how many X_2 responses are X_2X_2 or X_2-other in trial 2.

To measure the influence of the statement *Wrong* and the concomitant electric shock, the excess over chance of a response differing at the second trial from the initially punished response is computed.

Let X_s be a particular wrong response punished at any trial,

Let A be any response differing from the preceding response,

Let the order in which the symbols are written represent the history [2] of the response to a particular stimulus, and

Let G_x be the *a priori* chance that a response other than the preceding response will occur.

Then, the measure of the influence of a single punishment will be the relative magnitude of

$$\frac{X_sA}{X_sX_s + X_sA} - G_x.$$

For the individuals whose records are summarized in Table 2, we have

$$\frac{39 + 29}{(14 + 39) + (19 + 29)} = \frac{X_1A + X_2A}{(X_1X_1 + X_1A) + (X_2X_2 + X_2A)} = .67.$$

This is identical with the expression

$$\frac{X_sA}{X_sX_s + X_sA}.$$

If at the first trial a subject responded with X_1, at the second trial, he has, in addition to X_1, three other response

[2] Thus X_sX_sA means that in the first trial, the response was X_s; in the second trial, the response was again X_s; but in trial 3 the response was A, a response differing from X_s. X_sX_s may be X_1X_1 or X_2X_2.

TABLE 2

SYMBOLS—SET *A*: FREQUENCY OF THE SEQUENCES C_sC_s, C_sA, X_sX_s, X_sA, ETC. FOR TRIALS 1, 2, 3, 4, AND 5 BY SUBJECTS

	Ma	Ak	Mo	Tu	La	Le*	Fo	Du	Wi	Ha	Summary
At Trial 2											
C_1C_1	2	2	0	2	10	2	4	3	3	4	32
C_1 other	2	4	5	3	0	1	1	1	3	3	23
C_2C_2	0	2	5	2	0	2	5	2	6	1	25
C_2 other	1	1	3	1	0	5	4	1	2	1	19
X_1X_1	1	4	1	0	1	1	1	3	0	2	14
X_1 other	6	3	4	6	9	3	2	2	0	4	39
X_2X_2	2	1	1	3	0	3	2	3	2	2	19
X_2 other	6	3	1	3	0	3	1	5	4	3	29
At Trial 3											
$C_1C_1C_1$	1	0	0	0	9	2	3	1	3	1	20
C_1C_1 other	1	2	0	2	1	0	1	2	0	3	12
$C_2C_2C_2$	0	1	2	1	0	2	5	1	2	1	15
C_2C_2 other	0	1	3	1	0	0	0	1	4	0	10
$X_1X_1X_1$	1	1	0	0	0	0	1	2	0	2	7
X_1X_1 other	0	3	1	0	1	1	0	1	0	0	7
$X_2X_2X_2$	1	1	1	2	0	2	0	0	1	0	8
X_2X_2 other	1	0	0	1	0	1	2	3	1	2	11
At Trial 4											
$C_1C_1C_1C_1$	0	0	0	0	8	2	3	1	3	0	17
$C_1C_1C_1$ other	1	0	0	0	1	0	0	0	0	1	3
$C_2C_2C_2C_2$	0	1	2	1	0	2	4	0	2	0	12
$C_2C_2C_2$ other	0	0	0	0	0	0	1	1	0	1	3
$X_1X_1X_1X_1$	0	0	0	0	0	0	1	1	0	1	3
$X_1X_1X_1$ other	1	1	0	0	0	0	0	1	0	1	4
$X_2X_2X_2X_2$	1	1	0	1	0	0	0	0	1	0	4
$X_2X_2X_2$ other	0	0	1	1	0	2	0	0	0	0	4
At Trial 5											
$C_1C_1C_1C_1C_1$	0	0	0	0	8	1	2	1	3	0	15
$C_1C_1C_1C_1$ other	0	0	0	0	0	1	1	0	0	0	2
$C_2C_2C_2C_2C_2$	0	0	2	1	0	2	3	0	2	0	10
$C_2C_2C_2C_2$ other	0	1	0	0	0	0	1	0	0	0	2
$X_1X_1X_1X_1X_1$	0	0	0	0	0	0	1	0	0	0	1
$X_1X_1X_1X_1$ other	0	0	0	0	0	0	0	1	0	1	2
$X_2X_2X_2X_2X_2$	0	0	0	0	0	0	0	0	0	0	0
$X_2X_2X_2X_2$ other	1	1	0	1	0	0	0	0	1	0	4

* The complete record of Le's responses are given in Table 1.

which can be used. They are X_2, C_1, C_2. Thus the chances of obtaining a response other than the original wrong response are 3 out of 4. G_x is, therefore, .75.

This allowance, G_x, then is applied to correct for the influence of chance. We then have

$$\frac{68}{101} - .75 = -.08.$$

The influence of a single announcement of wrong with its concomitant electric shock is such as to cause this group of individuals to change from their originally wrong responses less often than we would expect by chance alone. There is, on the contrary, a certain perseverance in the particular response so punished.

By extension, the influence of two successive punishments for the same wrong will be measured by the relative magnitude of

$$\frac{X_sX_sA}{X_sX_sX_s + X_sX_sA} - G_x,$$

and for three successive punishments, and for four successive punishments for the same wrong, be measured by the relative magnitude of

$$\frac{X_sX_sX_sA}{X_sX_sX_sX_s + X_sX_sX_sA} - G_x \quad \text{and}$$

$$\frac{X_sX_sX_sX_sA}{X_sX_sX_sX_sX_s + X_sX_sX_sX_sA} - G_x, \quad \text{respectively.}$$

In a similar manner, a measure of the influence of single reward can be obtained. If chance alone were operating to determine the second response, a C_s in trial 1 for a particular stimulus would be followed by C_s in one fourth of the cases. Any excess over this proportion is due to, and is a measure of, the influence of a single rewarded response. If we

Let C_s be a specific right rewarded at any trial, and
A be any response differing from the preceding response, the order in which the symbols are written representing the history of the responses to a particular stimulus, and

G_c represent the *a priori* chance that the same response will be repeated.

Then the formulæ for the measurement of the influence of successive rewards are:

Number of Successive Repetitions and Rewards for the Same Right Response	Formulæ
one	$\frac{C_sC_s}{C_sC_s + C_sA} - G_c$
two	$\frac{C_sC_sC_s}{C_sC_sC_s + C_sC_sA} - G_c$
three	$\frac{C_sC_sC_sC_s}{C_sC_sC_sC_s + C_sC_sC_sA} - G_c$
four	$\frac{C_sC_sC_sC_sC_s}{C_sC_sC_sC_sC_s + C_sC_sC_sC_sA} - G_c$

These analyses result in tables such as Table 3. C_sC_s represents all those responses C_1C_1 and C_2C_2; C_sA those that are C_1A, C_2A; X_sX_s, those that are X_1X_1 and X_2X_2 etc. When the choice is among C_1, C_2, X_1, X_2, G_c is, of course, .25.

Table 3 is clear in showing that a C in trial 1 is followed by the same C in trial 2 more often than is likely by chance. The evidence is just as clear that an X is not less likely to occur after being punished. On the contrary, a punished response recurs more often than chance expectation. In a similar manner, we can trace through to trial 3 those responses which have been twice the same C, or which have been twice the same X; and so on for three and four repetitions of the same C or the same X.

Although the probability that fore-knowledge may influence results is small, there is some probability that prejudice or system may. If a subject has certain ideas about the stimulus, or preference among responses, these preferences may possibly operate to favor rewards, and to negate the influence of punishment.

Prejudice and system may be controlled by considering

TABLE 3

SYMBOLS—SET *A*: THE SUMMARY OF THE FREQUENCY OF THE SEQUENCES C_sC_s, C_sA, X_sX_s, X_sA, ETC. FOR TRIALS 1, 2, 3, 4, AND 5 WITH SUBTRACTIONS FOR *a priori* CHANCE *

	Number of Responses	Percent of All	The Excess in Percent over Chance at the Trial for Repetition of the Same Right Response	The Excess in Percent over Chance at the Trial for a Response Other than the Particular Wrong Response
At Trial 2				
C_sC_s	57	58	+ 33	
C_sA	42	42		
X_sX_s	33	33		
X_sA	68	67		− 08
At Trial 3				
$C_sC_sC_s$	35	61	+ 36	
C_sC_sA	22	39		
$X_sX_sX_s$	15	46		
X_sX_sA	18	54		− 21
At Trial 4				
$C_sC_sC_sC_s$	29	83	+ 58	
$C_sC_sC_sA$	6	17		
$X_sX_sX_sX_s$	7	47		
$X_sX_sX_sA$	8	53		− 22
At Trial 5				
$C_sC_sC_sC_sC_s$	25	86	+ 61	
$C_sC_sC_sC_sA$	4	14		
$X_sX_sX_sX_sX_s$	1	14		
$X_sX_sX_sX_sA$	6	86		+ 11

* The correction for the chance occurrence of the same response at a subsequent trial is .25. The correction for the chance occurrence of a response other than the particular response of a preceding trial is .75.

only those stimulus words the responses to which in trial 1 were right and so rewarded, and the responses to which in trial 2 were wrong and so punished, or those stimulus words the responses to which were wrong in trial 1, and responses to which in trial 2 were right.

Taking stimuli, the responses to which vary in trials 1 and 2, is in a measure, an indication that the first response was not maintained either through system or prejudice.

Then the formulæ that apply to measure the influence of successive rewards, and successive punishments are:

Successive Effects for the Same Response	Measure of the Influence of Successive Rights	Measure of the Influence of Successive Wrongs
one	$\frac{XC_sC_s}{XC_sC_s + XC_sA} - G_c$	$\frac{CX_sA}{CX_sX_s + CX_sA} - G_x$
two	$\frac{XC_sC_sC_s}{XC_sC_sC_s + XC_sC_sA} - G_c$	$\frac{CX_sX_sA}{CX_sX_sX_s + CX_sX_sA} - G_x$
three	$\frac{XC_sC_sC_sC_s}{XC_sC_sC_sC_s + XC_sC_sC_sA} - G_c$	$\frac{CX_sX_sX_sA}{CX_sX_sX_sX_s + CX_sX_sX_sA} - G_x$

We cumulated the sequences for those symbols for which there is evidence that nothing in the symbol was prepotent in determining the response. Such prepotency was ruled out by considering only those cases in which a right response in trial one was followed by a wrong response in trial 2, and those cases where a wrong response in trial one was followed by a right response in trial 2. Table 4 gives the history of those responses in a table comparable with Table 3.

The results shown in Table 4 demonstrate that any argument which explains the results of Table 3 in terms of prepotency, or prejudice, or system does not stand. We have collected instances in which the responses are chance and evanescent at trial one, as is evidenced by the response at trial 2. Comparison of these results show + .22, + .50, and + .68 for the increased efficacy of one, two, and three announcements of right plus concomitant money rewards, as compared with + .33, + .36, + .58, and − .23, + .06, and − .42 as compared with − .08, − .21, and − .22 as the influence of the announcement of one, two, and three wrongs plus concomitant electric shocks.

This is evidence, then, that punishing by saying *Wrong* for an incorrect response, makes the repetition of the same response more likely to recur when the same situation is again presented. This is contrary to expectation.

The average efficiency of a single *Right* to secure the repetition of the same right response based upon the unweighted average of the determinations derived from the C_sC_s and the $X_aC_sC_s$ analysis is + .21. The efficiency of a

TABLE 4

SYMBOLS—SET *A*: THE SUMMARY OF THE FREQUENCY OF THE SEQUENCES $X_aC_sC_s$, X_aC_sA, $C_aX_sX_s$, C_aX_sA, ETC. FOR TRIALS 1, 2, 3, 4, AND 5 WITH SUBTRACTIONS FOR *a priori* CHANCE

	Number of Responses	Percent of All	The Excess in Percent over Chance at the Trial for Repetition of the Same Right Response	The Excess in Percent over Chance at the Trial for a Response Other than the Particular Wrong Response
At Trial 3				
$X_aC_sC_s$	20	47	+ 22	
X_aC_sA	23	53		
$C_aX_sX_s$	16	48		
C_aX_sA	17	52		− 23
At Trial 4				
$X_aC_sC_sC_s$	15	75	+ 50	
$X_aC_sC_sA$	5	25		
$C_aX_sX_sX_s$	3	19		
$C_aX_sX_sA$	13	81		+ 06
At Trial 5				
$X_aC_sC_sC_sC_s$	14	93	+ 68	
$X_aC_sC_sC_sA$	1	07		
$C_aX_sX_sX_sX_s$	2	67		
$C_aX_sX_sX_sA$	1	33		− 42

single wrong to secure the elimination of the punished response is − .07.[3]

Weighting the results by the number of cases used at

[3] These measures of the efficiency of a single *Right* to secure the repetition of the rewarded response and of a single *Wrong* to secure the elimination of the punished response were secured as follows:

All the excesses over chance at trials 2, 3, 4, and 5 for the C_sC_s analysis are summed. The total is then divided by ten which is the number of rewarded responses preceding the particular response at trial 2, or 3, or 4, or 5 ($C_sC_s + C_sC_sC_s + C_sC_sC_sC_s + C_sC_sC_sC_sC_s$; 1, 2, 3, and 4 respectively). For the data of Table 3, this value is + 18.8. In a similar manner, the sum of the excesses over chance at trials 3, 4, and 5 are summed for the $X_aC_sC_s$ analysis and divided by 6, the number of rewarded responses preceding the particular response at trial 3, or 4, or 5. For the data of Table 4 this value is + 23.3. The average of these two determinations is used as a measure of the efficacy of a single *Right* to bring about the repetition of the rewarded response without reference to the number of responses upon which the excesses are determined.

When reference is made to the populations upon which the excess are determined similar but weighted averages are secured.

With the same procedure the value of the *Wrong* to secure elimination of the punished response is obtained.

arriving at each determination gives + .24 and − .10 for the value of a reward and a punishment, respectively.[4]

This, then, in general, is the method of analysis. Tables 1, 2, 3, and 4 were derived from Experiment One. We shall now report experiments with symbols to thought-of numbers.

Experiment One

In general, the subject was seated comfortably at a table. Dry electrodes of brass screening were placed on the subject's non-writing hand—one electrode over the upper joints of the three middle fingers, the other about the palm. These were secured by adhesive tape.[5] After the electrodes were secured, and the shock determined, the material was placed before him. The instructions were then read. If the subject was in doubt, the directions were read a second time. It was desirable (in order to save time and keep uniformity) that every subject should respond to the next line just as soon as he was told the *Right* or *Wrong* for the previous line. If the subject delayed, he was told: "Just guess any one as quickly as you can. You will learn better by guessing quickly than by stopping to think."

Symbols similar to those of Fig. 3 were presented twenty at a time for five trials as Set *A*. The order of presentation of the symbols was the same in trial 1 and in trial 5, but was random in trials 2, 3, and 4. Another group of twenty symbols similar, though different from those of Set *A* were presented in the same way. This second set was called Set *B*.

The following directions were given to each subject:

"This is a sort of guessing game. Each symbol represents two of the following numbers: 1 2 3 4. The two numbers that are correct for each symbol were determined by chance.

"When we begin, you will look at the first symbol, decide whether the response you wish to make is 1, 2, 3, or 4, then write the number you decide upon next to the symbol. If you are right, I will say *Right*, and give you one of these little tokens. Each is worth one-tenth of a cent. If you are wrong, I will say *Wrong* and give you a slight electric shock. The shock will not hurt you, but will be just uncomfortable enough to make you remember that the response was wrong.

"As soon as I say *Right* or *Wrong*, you will immediately decide on a response for the next symbol, writing the number next to it, etc. At the end of the period, I will give you one cent for every ten tokens you have earned. The game is to see how quickly you can learn one right response for each symbol and so get many symbols right, so get more money, and so receive fewer shocks."

Ten subjects, graduate students in Teachers College, participated in this experiment in April 1931. All subjects completed five trials with a set at one sitting. The

[4] We have attempted other systems of weights. Any reasonable system of weights will not change the direction of these tendencies. The data needed for any other determination are given in Tables 3 and 4.

[5] In these experiments, the electrodes led from a duBois-Reymond inductorium operating on four and a half volts, the secondary of which was placed at a point to secure the lifting of the bound hand ten times in succession to a make shock. With this technic, it was felt that variations in the secondary resistance and in the cathode surface were sufficiently accounted for. Compare Martin '12, p. 87.

records were then arranged so that the history of each response appeared on the line corresponding to the stimulus that provoked the response. The sample in Table 1 shows such a re-arranged record.

The facts for Set *A* have already been used as an illustration of the analysis. The improvement was from an average number right of 9.9 in trial 1 to 13.5 in trial 5—evidence that selective learning did occur. The data appear in Tables 2, 3, and 4. This same group improved on Set *B* from an initial score of 9.8 to a final score of 12.6. This is evidence of selective learning. We utilize the scores in the same way as for the preceding Set *A*.

Table 5 is comparable with Table 3 and Table 6 is comparable with Table 4.

TABLE 5

SYMBOLS—SET *B:* THE SUMMARY OF THE FREQUENCY OF THE SEQUENCES C_sC_s, C_sA, X_sX_s, X_sA, ETC. FOR TRIALS 1, 2, 3, 4, AND 5 WITH SUBTRACTIONS FOR *a priori* CHANCE

	Number of Responses	Percent of All	The Excess in Percent over Chance at the Trial for Repetition of the Same Right Response	The Excess in Percent over Chance at the Trial for a Response Other than the Particular Wrong Response
At Trial 2				
C_sC_s	45	46	+ 21	
C_sA	53	54		
X_sX_s	43	42		
X_sA	59	58		− 17
At Trial 3				
$C_sC_sC_s$	33	73	+ 48	
C_sC_sA	12	27		
$X_sX_sX_s$	16	37		
X_sX_sA	27	63		− 12.
At Trial 4				
$C_sC_sC_sC_s$	27	82	+ 57	
$C_sC_sC_sA$	6	18		
$X_sX_sX_sX_s$	11	68		
$X_sX_sX_sA$	5	32		− 43
At Trial 5				
$C_sC_sC_sC_sC_s$	20	74	+ 49	
$C_sC_sC_sC_sA$	7	26		
$X_sX_sX_sX_sX_s$	6	55		
$X_sX_sX_sX_sA$	5	45		− 30

TABLE 6

SYMBOLS—SET *B:* THE SUMMARY OF THE FREQUENCY OF THE SEQUENCES $X_aC_sC_s$ X_aC_sA, $C_aX_sX_s$, C_aX_sA, ETC. FOR TRIALS 1, 2, 3, 4, AND 5 WITH SUBTRACTIONS FOR *a priori* CHANCE

	Number of Responses	Percent of All	The Excess in Percent over Chance at the Trial for Repetition of the Same Right Response	The Excess in Percent over Chance at the Trial for a Response Other than the Particular Wrong Response
At Trial 3				
$X_aC_sC_s$	15	35	+ 10	
X_aC_sA	28	65		
$C_aX_sX_s$	12	35		
C_aX_sA	22	65		− 10
At Trial 4				
$X_aC_sC_sC_s$	7	47	+ 22	
$X_aC_sC_sA$	8	53		
$C_aX_sX_sX_s$	4	33		
$C_aX_sX_sA$	8	67		− 08
At Trial 5				
$X_aC_sC_sC_sC_s$	6	86	+ 61	
$X_aC_sC_sC_sA$	1	14		
$C_aX_sX_sX_sX_s$	2	50		
$C_aX_sX_sX_sA$	2	50		− 25

In May 1931 two other groups of ten subjects each participated in this same experiment doing Set *A* in one sitting. These groups improved in five trials from 10.7 to 11.3, and from 10.0 to 12.1, respectively. The group that did Set *A* and then Set *B* improved on Set *A* from 9.9 to 13.5. For the three groups with Set *A*, we have the improvement given as from 10.1 to 12.4 in five trials.

Table 7 shows the results for the combined group (thirty subjects) on the C_sC_s X_sX_s analysis. Table 8 shows, for the same combined groups, the results of the X C_sC_s and C X_sX_s analysis.

Weighting the results of Table 7 (by the number of groups of ten comprising it) with a weight of three and of Table 5 with a weight of one, we have $+ .21\frac{1}{2}$, $+ .30\frac{3}{4}$, $+ .50\frac{3}{4}$, $+ .58\frac{3}{4}$ for the influence of one, two, three, and four successive C_s's, respectively, and $- .08\frac{3}{4}$, $- .19\frac{3}{4}$, $- .36\frac{1}{4}$, $- .23\frac{1}{4}$, for the influence of one, two, three and four X_s's respectively.

TABLE 7

SYMBOLS—SET *A:* THE SUMMARY OF THE FREQUENCY OF THE SEQUENCES *CC*, *CA*, *XX*, *XA*, ETC. FOR TRIALS 1, 2, 3, 4, AND 5 WITH SUBTRACTIONS FOR *a priori* CHANCE: ALL GROUPS COMBINED ($n = 30$)

	Number of Responses	Percent of All	The Excess in Percent over Chance at the Trial for Repetition of the Same Right Response	The Excess in Percent over Chance at the Trial for a Response Other than the Particular Wrong Response
At Trial 2				
C_sC_s	143	47	+ 22	
C_sA	164	53		
X_sX_s	89	31		
X_sA	204	69		− 06
At Trial 3				
$C_sC_sC_s$	71	50	+ 25	
C_sC_sA	72	50		
$X_sX_sX_s$	41	46		
X_sX_sA	48	54		− 21
At Trial 4				
$C_sC_sC_sC_s$	52	73	+ 48	
$C_sC_sC_sA$	19	27		
$X_sX_sX_sX_s$	24	59		
$X_sX_sX_sA$	17	41		− 34
At Trial 5				
$C_sC_sC_sC_sC_s$	45	87	+ 62	
$C_sC_sC_sC_sA$	7	13		
$X_sX_sX_sX_sX_s$	11	46		
$X_sX_sX_sX_sA$	13	54		− 21

From Tables 6 and 8 with similar weights we have + .08½, + .25¾, + .62½ respectively, for the influence of one, two, and three C_s's, and − .10¾, − .04¼, − .28¾ respectively for the influence of one, two and three X_s's, respectively.

The unweighted average values of a rewarded right are + .16 and + .16 according to the C_sC_s and $X\ C_sC_s$ analyses, respectively, and of a punished wrong are − .08 and − .07 by the X_sX_s and $C\ X_sX_s$ analyses, respectively.

Experiments with nonsense words to meaningful English words were performed to check on these results.

TABLE 8

SYMBOLS—SET *A*: THE SUMMARY OF THE FREQUENCY OF THE SEQUENCES $X_aC_sC_s$, X_aC_sA, $C_aX_sX_s$, C_aX_sA, ETC. FOR TRIALS 1, 2, 3, 4, AND 5 WITH SUBTRACTIONS FOR *a priori* CHANCE: ALL GROUPS COMBINED ($n = 30$)

	Number of Responses	Percent of All	The Excess in Percent over Chance at the Trial for Repetition of the Same Right Response	The Excess in Percent over Chance at the Trial for a Response Other than the Particular Wrong Response
At Trial 3				
$X_aC_sC_s$	46	33	+ 08	
X_aC_sA	93	67		
$C_aX_sX_s$	39	36		
C_aX_sA	70	64		− 11
At Trial 4				
$X_aC_sC_sC_s$	24	52	+ 27	
$X_aC_sC_sA$	22	48		
$C_aX_sX_sX_s$	11	28		
$C_aX_sX_sA$	28	72		− 03
At Trial 5				
$X_aC_sC_sC_sC_s$	21	88	+ 63	
$X_aC_sC_sC_sA$	3	12		
$C_aX_sX_sX_sX_s$	6	55		
$C_aX_sX_sX_sA$	5	45		− 30

EXPERIMENT TWO

A code word followed by four English words on the same line constituted the stimulus unit. Twenty such units were presented on a page. Presentation of five identical pages was called a set. There were four such sets—*A*, *B*, *C*, and *D*.

Each subject was seated comfortably at a table. Dry electrodes of brass screening leading from an inductorium were placed on the subject's non-writing hand—one over the three middle fingers, the other about the lower palm.

The following directions were given to each subject:

"Look at the first word in the first line. It is a code word which has two equivalents. The two equivalents are among the group of four words following the code word.

"When we begin, you will choose one word that you think is an equivalent for the code word at the beginning of the line. If you are right, I will say *Right* and give you one of these little tokens. Each is worth one-tenth of a cent. If you are wrong, I shall say *Wrong* and give you a slight electric shock. The shock will not hurt you, but will be just uncomfortable enough to make you remember that the response was wrong.

"As soon as I say *Right* or *Wrong*, you will immediately choose an equivalent for the second code word on the next line, and draw a line under it, and so on.

"At the end of the period, I will give you one cent for each ten tokens you have earned. The task is to see how quickly you can learn one equivalent for each code word, so as to learn many code equivalents, and so make more money, and receive fewer shocks."

Ten subjects, graduate students in Teachers College, participated in this experiment during April, 1931. All subjects completed the five trials of each set at one sitting. Ten additional subjects participated in this experiment later in the same month, also doing Set *A* and Set *B*. Ten more subjects participated in this same experiment in April and May 1931, doing Set *C* and Set *D*.

Experiment 2 differed in no wise from Experiment 1 except in the materials used and in the number of subjects used.

The three groups improved with these materials, as evidenced by the following means:

	Set *A*		Set *B*	
	Initial	Final	Initial	Final
Group I	10.3	13.7	11.0	16.1
Group II	10.8	13.0	10.0	13.5
	Set *C*		Set *D*	
	Initial	Final	Initial	Final
Group III	9.7	13.1	10.3	14.4

We then use these records and compile tables like 7 and 8 for all subjects. Table 9 gives the data by the C_sC_s analysis for thirty subjects on two sets each giving an effective population of sixty. Table 10 gives the results by the $X\ C_sC_s$ analysis.

The unweighted values of a single rewarded right are $+ .22$ and $+ .24$ by C_sC_s and $X\ C_sC_s$ analysis respectively, and of a single punished wrong are $- .09$ and $- .11\frac{1}{2}$ by X_sX_s and $C\ X_sX_s$ respectively.

Another experiment with the Spanish words used by Thorndike was performed.

Experiment Three

The Spanish Vocabulary used by Thorndike consisted of two hundred Spanish words each of which was followed by five English words, one of which meant the same or nearly the same as the Spanish word at the beginning of the line. Figure 1 gives a sample of this material.

TABLE 9

CODE WORDS—SETS *A, B, C, D:* THE SUMMARY OF THE FREQUENCY OF THE SEQUENCES C_sC_s, C_sA, X_sX_s, X_sA, ETC. FOR TRIALS 1, 2, 3, 4, AND 5 WITH SUBTRACTIONS FOR *a priori* CHANCE: ALL GROUPS COMBINED ($n = 30$)

	Number of Responses	Percent of All	The Excess in Percent over Chance at the Trial for Repetition of the Same Right Response	The Excess in Percent over Chance at the Trial for a Response Other than the Particular Wrong Response
At Trial 2				
C_sC_s	333	54	+ 29	
C_sA	288	46		
X_sX_s	210	36		
X_sA	369	64		− 11
At Trial 3				
$C_sC_sC_s$	257	77	+ 52	
C_sC_sA	76	23		
$X_sX_sX_s$	86	41		
X_sX_sA	124	59		− 16
At Trial 4				
$C_sC_sC_sC_s$	230	89½	+ 64½	
$C_sC_sC_sA$	27	10½		
$X_sX_sX_sX_s$	41	48		
$X_sX_sX_sA$	45	52		− 23
At Trial 5				
$C_sC_sC_sC_sC_s$	222	96½	+ 71½	
$C_sC_sC_sC_sA$	8	3½		
$X_sX_sX_sX_sX_s$	24	66		
$X_sX_sX_sX_sA$	17	34		− 41

The material was presented so that a trial consisted of 200 words. Five trials with identical pages were given to each subject.

Each subject was seated comfortably at a table. Brass screening dry electrodes from an inductorium were placed on the subject's non-writing hand—one over the three middle fingers, the other about the lower palm.

The following directions were given to each subject:

"These are Spanish words. You will look at the first line, decide which word you think is right, and underline it. If you are right, I will say *Right.* If you are wrong, I will say *Wrong* and give you a slight electric shock. The shock will not hurt you, but will be just uncomfortable enough to make you remember that the response is wrong.

"As soon as I say *Right* or *Wrong*, you will immediately choose a word from the next line and draw a line under it, and so on.

"The idea is to see how quickly you can learn the correct equivalent for each Spanish word so as to get many Spanish words right and so receive fewer shocks."

TABLE 10

CODE WORDS—SETS *A, B, C, D:* THE SUMMARY OF THE FREQUENCY OF THE SEQUENCES $X_aC_sC_s$, X_aC_sA, $C_aX_sX_s$, C_aX_sA, ETC. FOR TRIALS 1, 2, 3, 4, AND 5 WITH SUBTRACTIONS FOR *a priori* CHANCE: ALL GROUPS COMBINED ($n = 30$)

	Number of Responses	Percent of All	The Excess in Percent over Chance at the Trial for Repetition of the Same Right Response	The Excess in Percent over Chance at the Trial for a Response Other than the Particular Wrong Response
At Trial 3				
$X_aC_sC_s$	125	52	+ 27	
X_aC_sA	116	48		
$C_aX_sX_s$	70	34		
C_aX_sA	135	66		− 09
At Trial 4				
$X_aC_sC_sC_s$	98	78	+ 53	
$X_aC_sC_sA$	27	22		
$C_aX_sX_sX_s$	35	50		
$C_aX_sX_sA$	35	50		− 25
At Trial 5				
$X_aC_sC_sC_sC_s$	87	89	+ 64	
$X_aC_sC_sC_sA$	11	11		
$C_aX_sX_sX_sX_s$	21	60		
$C_aX_sX_sX_sA$	14	40		− 35

Ten subjects, graduate students in Teachers College, participated in this experiment during May and June, 1931. Each subject completed all five trials at one sitting. There was an average gain from 38.6 words right in trial 1 to 70.9 right in trial 5.

The analysis yields two tables: Table 11 is derived from the C_sC_s and X_sX_s analysis. Table 12 is derived from the $X\ C_sC_s$ and $C\ X_sX_s$ analysis.

These two tables substantiate the generalization inferred from the preceding two experiments. A rewarded response insures the repetition of the response so rewarded, although punishment does not eliminate the punished response from the repertory.

The unweighted average values of a single rewarded response are + .21 and + .24 by the two methods. The unweighted average values of a single punished response are respectively − .05 and − .05.

TABLE 11

SPANISH WORDS: THE SUMMARY OF THE FREQUENCY OF THE SEQUENCES C_sC_s, C_sA, X_sX_s, X_sA, ETC. FOR TRIALS 1, 2, 3, 4 AND 5 WITH SUBTRACTIONS FOR *a priori* CHANCE:* ALL GROUPS COMBINED ($n = 30$)

	Number of Responses	Percent of All	The Excess in Percent over Chance at the Trial for Repetition of the Same Right Response	The Excess in Percent over Chance at the Trial for a Response Other than the Particular Wrong Response
At Trial 2				
C_sC_s	175	45.3	+ 25.3	
C_sA	211	54.7		
X_sX_s	436	27.0		
X_sA	1178	73.0		− 07.0
At Trial 3				
$C_sC_sC_s$	118	67.4	+ 47.4	
C_sC_sA	57	32.6		
$X_sX_sX_s$	145	33.3		
X_sX_sA	291	66.7		− 13.3
At Trial 4				
$C_sC_sC_sC_s$	98	83.1	+ 63.1	
$C_sC_sC_sA$	20	16.9		
$X_sX_sX_sX_s$	45	31.0		
$X_sX_sX_sA$	100	69.0		− 11.0
At Trial 5				
$C_sC_sC_sC_sC_s$	89	90.8	+ 70.8	
$C_sC_sC_sC_sA$	9	09.2		
$X_sX_sX_sX_sX_s$	19	42.2		
$X_sX_sX_sX_sA$	26	57.8		− 22.2

* Since there are five possibilities, the chances for the repetition of C_s are one in five or .20; the chances for a response other than a particular X_s are four in five, or .80.

EXPERIMENT FOUR

Materials *a*, *b*, *c*, *d*, *e*, *f*, *g*, and *h* were used in Experiment 4.
Material *a* consisted of 20 lines of symbols, 4 to a line, like that in figure 4;
Material *e* consisted of the same symbols in a changed order;
Material *b* consisted of 20 lines of di-letters, 4 to a line, like that in figure 5;
Material *f* consisted of the same di-letters in a changed order;
Material *c* consisted of 20 lines of symbols, 4 symbols to a line;
Material *g* consisted of the same symbols in a changed order;
Material *d* consisted of 20 lines of di-letters, 4 to a line;
Material *h* consisted of the same di-letters in a changed order.

The material was presented in four sets of five trials each. Each set was alter-

TABLE 12

SPANISH WORDS: SUMMARY OF THE FREQUENCY OF THE SEQUENCES $X_aC_sC_s$, X_aC_sA, $C_aX_sX_s$, C_aX_sA, ETC. FOR TRIALS 1, 2, 3, 4, AND 5 WITH SUBTRACTIONS FOR *a priori* CHANCE

	Number of Responses	Percent of All	The Excess in Percent over Chance at the Trial for Repetition of the Same Right Response	The Excess in Percent over Chance at the Trial for a Response Other than the Particular Wrong Response
At Trial 3				
$X_aC_sC_s$	141	45.3	+ 25.3	
X_aC_sA	170	54.7		
$C_aX_sX_s$	52	24.6		
C_aX_sA	159	75.4		− 04.6
At Trial 4				
$X_aC_sC_sC_s$	105	74.5	+ 54.5	
$X_aC_sC_sA$	36	25.5		
$C_aX_sX_sX_s$	11	21.2		
$C_aX_sX_sA$	41	78.8		− 01.2
At Trial 5				
$X_aC_sC_sC_sC_s$	86	81.9	+ 61.9	
$X_aC_sC_sC_sA$	19	18.1		
$C_aX_sX_sX_sX_s$	5	45.5		
$C_aX_sX_sX_sA$	6	54.5		− 25.5

nately one of symbols and one of di-letters. The order in which these trials were given was

	Set *A*— Symbols	Set *B*— Di-Letters	Set *C*— Symbols	Set *D*— Di-Letters
Trial 1	*a*	*b*	*c*	*d*
Trial 2	*a*	*b*	*c*	*d*
Trial 3	*e*	*f*	*g*	*h*
Trial 4	*a*	*f*	*c*	*h*
Trial 5	*e*	*b*	*g*	*d*

Each subject was seated comfortably at a table. Brass screening dry electrodes from an inductorium were placed on the subject's non-writing hand—one over the three middle fingers, the other about the lower palm.

The following directions were given to each subject:

"This is a sort of a guessing game. Two of the figures in each row of four are right. The other two are wrong. The rights are right by chance, having been determined arbitrarily by successive throws of dice. When we begin, you will look at the first row and choose one that you think is right, and draw a line under it. If you are right, I will say *Right* and give you one of these little tokens. Each is worth one-tenth of a cent. If you are wrong, I shall say *Wrong* and give you a slight electric

shock. The shock will not hurt you, but will be just uncomfortable enough to make you remember that your response was wrong.

"As soon as I say *Right* or *Wrong*, you will immediately choose one from the next line and draw a line under it, and so on.

"At the end of the period, I will give you one cent for every ten tokens that you have earned. The game is to see how quickly you can learn one right response in each line, so as to get many lines right, and so make more money and receive fewer shocks."

It was desirable (in order to save time and to keep uniformity) that every subject should respond to the next line just as soon as he received the signal of right or wrong for the previous lines. If the subject delayed, he was told:

"Just guess any one as quickly as you can. You will learn better by guessing quickly than by stopping to think."

As soon as the subject had responded to the twenty lines of a sheet of Set *A*, the next page was presented—until the five pages of Set *A* were done. The tokens were converted into money at the end of each page of work.

In a similar manner, Sets *B*, *C*, and *D* were administered.

TABLE 13

SYMBOLS—SETS *A* AND *C:* THE SUMMARY OF THE FREQUENCY OF THE SEQUENCES C_sC_s, C_sA, X_sX_s, X_sA, ETC. FOR TRIALS 1, 2, 3, 4 AND 5 WITH SUBTRACTIONS FOR *a priori* CHANCE

	Number of Responses	Percent of All	The Excess in Percent over Chance at the Trial for Repetition of the Same Right Response	The Excess in Percent over Chance at the Trial for a Response Other than the Particular Wrong Response
At Trial 2				
C_sC_s	122	58	+ 33	
C_sA	89	42		
X_sX_s	80	42		
X_sA	109	58		− 17
At Trial 3				
$C_sC_sC_s$	81	66	+ 41	
C_sC_sA	41	34		
$X_sX_sX_s$	43	54		
X_sX_sA	37	46		− 29
At Trial 4				
$C_sC_sC_sC_s$	68	84	+ 59	
$C_sC_sC_sA$	13	16		
$X_sX_sX_sX_s$	25	58		
$X_sX_sX_sA$	18	42		− 33
At Trial 5				
$C_sC_sC_sC_sC_s$	64	94	+ 69	
$C_sC_sC_sC_sA$	4	06		
$X_sX_sX_sX_sX_s$	14	56		
$X_sX_sX_sX_sA$	11	44		− 31

Ten subjects, graduate students in Teachers College, participated in this experiment during April 1931. Each subject completed the five trials of each of the four sets of this experiment at one sitting.

For the symbols, the average number of rights on Set *A* increased from 10.9 in trial 1 to 12.0 in trial 5, and on Set *C*, from 10.2 to 13.5. For the di-letters, the corresponding increases on Set *B* were from 10.3 to 11.5 and on Set *D*, from 9.3 to 13.9.

For these ten subjects, then, there are four tables presenting the analyses: Tables 13 and 14 for nonsense symbols; Tables 15 and 16 for the di-letters.

TABLE 14

SYMBOLS—SETS *A* AND *C*: THE SUMMARY OF THE FREQUENCY OF THE SEQUENCES $X_aC_sC_s$, X_aC_sA, $C_aX_sX_s$, C_aX_sA, ETC. FOR TRIALS 1, 2, 3, 4, AND 5 WITH SUBTRACTIONS FOR *a priori* CHANCE

	Number of Responses	Percent of All	The Excess in Percent over Chance at the Trial for Repetition of the Same Right Response	The Excess in Percent over Chance at the Trial for a Response Other than the Particular Wrong Response
At Trial 3				
$X_aC_sC_s$	42	50	+ 25	
X_aC_sA	42	50		
$C_aX_sX_s$	28	47		
C_aX_sA	31	53		− 22
At Trial 4				
$X_aC_sC_sC_s$	21	50	+ 25	
$X_aC_sC_sA$	21	50		
$C_aX_sX_sX_s$	13	47		
$C_aX_sX_sA$	15	53		− 22
At Trial 5				
$X_aC_sC_sC_sC_s$	20	95	+ 70	
$X_aC_sC_sC_sA$	1	05		
$C_aX_sX_sX_sX_s$	7	54		
$C_aX_sX_sX_sA$	6	46		− 29

Through the courtesy of Mr. Jacob Tuckman, data are available from ten unsophisticated subjects to whom he administered the four sets of Experiment four. The administration was identical with that used for the adult group.

There is nothing in the experience of these boys, whose ages range from $12\frac{1}{2}$ to 14 years, to cause them to prefer to receive electric shocks. For such a group of naïve subjects, punishments, if it has any of its alleged potency, ought to eliminate wrong responses so punished. This is not so. Although the

TABLE 15

DI-LETTERS—SETS *B* AND *D*: THE SUMMARY OF THE FREQUENCY OF THE SEQUENCES C_sC_s, C_sA, X_sX_s, X_sA, ETC. FOR TRIALS 1, 2, 3, 4, AND 5 WITH SUBTRACTIONS FOR *a priori* CHANCE

	Number of Responses	Percent of All	The Excess in Percent over Chance at the Trial for Repetition of the Same Right Response	The Excess in Percent over Chance at the Trial for a Response Other than the Particular Wrong Response
At Trial 2				
C_sC_s	130	66	+ 41	
C_sA	67	34		
X_sX_s	69	34		
X_sA	134	66		− 09
At Trial 3				
$C_sC_sC_s$	92	71	+ 46	
C_sC_sA	38	29		
$X_sX_sX_s$	33	48		
X_sX_sA	36	52		− 23
At Trial 4				
$C_sC_sC_sC_s$	72	78	+ 53	
$C_sC_sC_sA$	20	22		
$X_sX_sX_sX_s$	18	55		
$X_sX_sX_sA$	15	45		− 30
At Trial 5				
$C_sC_sC_sC_sC_s$	65	90	+ 65	
$C_sC_sC_sC_sA$	7	10		
$X_sX_sX_sX_sX_s$	12	67		
$X_sX_sX_sX_sA$	6	33		− 42

learning for the nonsense symbols shows gains of + 1.8 and + 3.3 right responses, the wrong responses do more harm by occurring than punishment can offset by causing a shift to any other response. The same facts are found for the di-letters. The gains on the di-letters are + 1.6 and + 2.5.

Tables 17 and 18 gives the results for the nonsense symbols, Tables 19 and 20 for the di-letters.

The average unweighted values of a single reward and of a single punishment for the boys and the adults on di-letters and on symbols are given in the Table below (Table 21).

TABLE 16

DI-LETTERS—SETS *B* AND *D:* THE SUMMARY OF THE FREQUENCY OF THE SEQUENCES $X_aC_sC_s$, X_aC_sA, $C_aX_sX_s$, C_aX_sA, ETC. FOR TRIALS 1, 2, 3, 4, AND 5 WITH SUBTRACTIONS FOR *a priori* CHANCE

	Number of Responses	Percent of All	The Excess in Percent over Chance at the Trial for Repetition of the Same Right Response	The Excess in Percent over Chance at the Trial for a Response Other than the Particular Wrong Response
At Trial 3				
$X_aC_sC_s$	57	63	+ 38	
X_aC_sA	34	37		
$C_aX_sX_s$	21	44		
C_aX_sA	27	56		− 19
At Trial 4				
$X_aC_sC_sC_s$	42	74	+ 49	
$X_aC_sC_sA$	15	26		
$C_aX_sX_sX_s$	13	60		
$C_aX_sX_sA$	8	40		− 35
At Trial 5				
$X_aC_sC_sC_sC_s$	37	88	+ 63	
$X_aC_sC_sC_sA$	5	12		
$C_aX_sX_sX_sX_s$	8	57		
$C_aX_sX_sX_sA$	6	43		− 32

The efficacy of a reward and of a punishment is not primarily a function of the age or sophistication of those experiencing the incentives. Rewards may be depended upon to bring about learning. Accumulation of results such as these is not mere heaping of Ossa on Pelion. The consistency of the results from diverse materials and from diverse groups points to the universality of the generalization. Nothing in these data can favor the belief that a punished response eliminates itself faster than chance alone eliminates it. All our results indicate that whatever total improve-

ment occurs is due to the efficacy of a reward in bringing about the repetition of the response so rewarded.

This paper has analyzed the results from experiments with a hundred subjects learning diverse materials. Consistently,

TABLE 17*

SYMBOLS: THE SUMMARY OF THE FREQUENCY OF THE SEQUENCES C_sC_s, C_sA, X_sX_s, X_sA, ETC. FOR TRIALS 1, 2, 3, 4, AND 5 WITH SUBTRACTIONS FOR *a priori* CHANCE

	Number of Responses	Percent of All	The Excess in Percent over Chance at the Trial for Repetition of the Same Right Response	The Excess in Percent over Chance at the Trial for a Response Other than the Particular Wrong Response
At Trial 2				
C_sC_s	90	47	+ 22	
C_sA	101	53		
X_sX_s	66	31		
X_sA	143	69		− 06
At Trial 3				
$C_sC_sC_s$	59	65	+ 40	
C_sC_sA	31	35		
$X_sX_sX_s$	39	59		
X_sX_sA	27	41		− 34
At Trial 4				
$C_sC_sC_sC_s$	47	80	+ 55	
$C_sC_sC_sA$	12	20		
$X_sX_sX_sX_s$	27	70		
$X_sX_sX_sA$	12	30		− 45
At Trial 5				
$C_sC_sC_sC_sC_s$	40	85	+ 60	
$C_sC_sC_sC_sA$	7	15		
$X_sX_sX_sX_sX_s$	22	82		
$X_sX_sX_sX_sA$	5	18		− 57

* From the data of Jacob Tuckman.

the finding has been that a wrong response does more harm by occurring than the punishment can offset. The positive value of the reward was demonstrated consistently as high and significant.

We have intensified rewards and punishments. We have duplicated Thorndike's experiments with Spanish words using

intensified punishment and reward. We have found no difference between the value of a symbolic punishment according to Thorndike and an intensified punishment as administered in this experiment. A constant intensification does not increase the potency of punishment, symbolic or otherwise.

TABLE 18 *

SYMBOLS: THE SUMMARY OF THE FREQUENCY OF THE SEQUENCES $X_aC_sC_s$, X_aC_sA, $C_aX_sX_s$, C_aX_sA, ETC. FOR TRIALS 1, 2, 3, 4, AND 5 WITH SUBTRACTIONS FOR *a priori* CHANCE

	Number of Responses	Percent of All	The Excess in Percent over Chance at the Trial for Repetition of the Same Right Response	The Excess in Percent over Chance at the Trial for a Response Other than the Particular Wrong Response
At Trial 3				
$X_aC_sC_s$	47	46	+ 21	
X_aC_sA	56	54		
$C_aX_sX_s$	19	30		
C_aX_sA	44	70		− 05
At Trial 4				
$X_aC_sC_sC_s$	30	64	+ 39	
$X_aC_sC_sA$	17	36		
$C_aX_sX_sX_s$	8	42		
$C_aX_sX_sA$	11	58		− 17
At Trial 5				
$X_aC_sC_sC_sC_s$	20	67	+ 42	
$X_aC_sC_sC_sA$	10	33		
$C_aX_sX_sX_sX_s$	6	75		
$C_aX_sX_sX_sA$	2	25		− 50

* From the data of Jacob Tuckman.

TABLE 19*

DI-LETTERS: THE SUMMARY OF THE FREQUENCY OF THE SEQUENCES C_sC_s, C_sA, X_sX_s, X_sA, ETC. FOR TRIALS 1, 2, 3, 4, AND 5 WITH SUBTRACTIONS FOR *a priori* CHANCE

	Number of Responses	Percent of All	The Excess in Percent over Chance at the Trial for Repetition of the Same Right Response	The Excess in Percent over Chance at the Trial for a Response Other than the Particular Wrong Response
At Trial 2				
C_sC_s	113	58	+ 33	
C_sA	83	42		
X_sX_s	83	41		
X_sA	121	59		− 16
At Trial 3				
$C_sC_sC_s$	66	58	+ 33	
C_sC_sA	47	42		
$X_sX_sX_s$	38	46		
X_sX_sA	45	54		− 21
At Trial 4				
$C_sC_sC_sC_s$	59	89	+ 64	
$C_sC_sC_sA$	7	11		
$X_sX_sX_sX_s$	22	58		
$X_sX_sX_sA$	16	42		− 33
At Trial 5				
$C_sC_sC_sC_sC_s$	52	88	+ 63	
$C_sC_sC_sC_sA$	7	12		
$X_sX_sX_sX_sX_s$	12	55		
$X_sX_sX_sX_sA$	10	45		− 30

* From the data of Jacob Tuckman.

TABLE 20*

DI-LETTERS: THE SUMMARY OF THE FREQUENCY OF THE SEQUENCES $X_aC_sC_s$, X_aC_sA, $C_aX_sX_s$, C_aX_sA, ETC. FOR TRIALS 1, 2, 3, 4, AND 5 WITH SUBTRACTIONS FOR *a priori* CHANCE

	Number of Responses	Percent of All	The Excess in Percent over Chance at the Trial for Repetition of the Same Right Response	The Excess in Percent over Chance at the Trial for a Response Other than the Particular Wrong Response
At Trial 3				
$X_aC_sC_s$	37	45	+ 20	
X_aC_sA	44	55		
$C_aX_sX_s$	16	33		
C_aX_sA	32	67		− 08
At Trial 4				
$X_aC_sC_sC_s$	18	49	+ 24	
$X_aC_sC_sA$	19	51		
$C_aX_sX_sX_s$	8	50		
$C_aX_sX_sA$	8	50		− 25
At Trial 5				
$X_aC_sC_sC_sC_s$	12	67	+ 42	
$X_aC_sC_sC_sA$	6	33		
$C_aX_sX_sX_sX_s$	6	75		
$C_aX_sX_sX_sA$	2	25		− 50

* From the data of Jacob Tuckman.

TABLE 21

THE AVERAGE UNWEIGHTED VALUE OF A SINGLE PUNISHMENT AND OF A SINGLE REWARD, DERIVED FROM EXPERIMENT 4

Group	Type of Analysis	Symbols		Di-Letters	
		Reward	Punishment	Reward	Punishment
Adults	C_sC_s and X_sX_s	+ 20	− 11	+ 21	− 10
Adults	$X_aC_sC_s$ and $C_aX_sX_s$	+ 20	− 12	+ 25	− 14
Boys	C_sC_s and X_sX_s	+ 18	− 14	+ 19	− 10
Boys	$X_aC_sC_s$ and $C_aX_sX_s$	+ 17	− 12	+ 14	− 14

REFERENCES

MARTIN, ERNEST G., '12, The Measurement of Induction Shocks. John Wiley and Sons, New York, vii + 117.

THORNDIKE, EDWARD L., '32, Fundamentals of Learning. Bureau of Publications, Teachers College, Columbia University, New York (in press).

RATE AND DIRECTION OF THE CONTRACTION WAVE IN MUSCLE DURING VOLUNTARY AND REFLEX MOVEMENT

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Introduction.—Although the velocity of the nerve impulse has been the subject of experimentation since Helmholtz' first measurement in 1850, the velocity of the contraction wave in muscle has attracted relatively little attention. Dodge (**2**), using the muscle thickening technique, computed the velocity of the wave of contraction in reflex activity as about 60 m per second for the quadriceps femoris muscle. All the evidence from his records was against the wave of contraction proceeding up the muscle from the distal end. The general course of the contraction wave was from above downwards. This phenomenon was best seen by Dodge in a group of simultaneous photographic shadow records. Adrian (**1**) suggested a possible technique for the measurement of the contraction wave's velocity, but to our knowledge he has published no report of his application of this technique. As the active region of a contracting muscle passes first under one electrode and then under another, the current of the galvanometer will travel first one way and then the other, forming the ordinary diphasic response, and the rate of conduction may be calculated from the interval between the phases and the distance between the electrodes.

When the present study was in progress, Golla and Antonovitch (**4**), using the action current technique, reported the velocity of the wave of conduction in the quadriceps femoris group of muscles in reflex activity as a relatively minor part of a study of conduction rate in human motor nerves. No mention was made of the number of subjects used, of the variability from individual to individual, or of the variability within the records from a given individual. The level of

entry of the nerve, or the 'nervous equator' of the muscle was determined by leading off from the muscle action currents with two pairs of needle electrodes set 2 cm apart, moved successively from a proximal position near the muscle's origin to within a short distance from the upper border of the patella. In a muscle measuring 43 cm in length, the nervous equator was found to be represented by a transverse band, 3 cm broad, lying about 14 cm below the anterior superior spine of the ilium. Above this band, the electrical response travels upwards; below it, it travels downwards. Contraction reached all points on any particular transverse level of the muscle simultaneously. By placing both pairs of electrodes 12 cm apart below or above the nervous equator, so that the response would be unidirectional, the velocity of the contraction wave could be determined. The rate was found to be 29 m per second.

The aims of the present study were: (1) the determination of the central tendency and variability of the rate of the contraction wave in different muscles during reflex and voluntary activity in a sufficient number of cases to warrant conclusions; (2) the observation of the direction and nature of the contraction.

Apparatus and Method.—We utilized the action current technique. The recording apparatus consisted of two perfectly matched, non-interfering, three stage resistance-coupled amplifiers, a Westinghouse oscillograph, a General Radio low frequency, type 377-B, oscillator, and a signal circuit.

This apparatus was used for the simultaneous recording of the latent periods of reflex and voluntary movements at two different points on the executant muscle. The stimulus for the reflex was the tapping by an iron mallet of a brass strip fastened over the tendon (Achilles or patellar) and insulated from it by a small block of wood and a rubber dam. The contact of the iron mallet with the brass strip actuated the signal circuit and discharged a previously charged condenser through one element of the oscillograph. The latent period was represented by the interval of time elapsing between the stimulation and the appearance of the first action current wave. The action currents were picked up at each point on the muscle by a pair of thin brass electrodes covered by Canton flannel which was moistened by a saturated salt solution. The brass strips in each pair of electrodes were 11 mm wide, 69 mm long and 8 mm apart. They were curved to conform to the curvature of the muscle and held in place by rubber bands. The electrodes were so arranged that a unidirectional wave passing through the muscle would produce action currents in phase. The action currents from each point were equally amplified on a record by the two matched amplifiers and oscillograph elements. A time line of sine wave oscillations at 1000 ~ was supplied by the os-

cillator. A special photographic unit recorded the signal, two action current lines, and the time line on Eastman 35 mm No. 1 sensitized paper.

The rate of conduction was determined by obtaining the ratio between the difference in the latent periods at two points on the surface of the muscle and the distance between these two points. It was studied for two groups of muscles, the quadriceps femoris and gastrocnemius, in both reflex and voluntary activity. In general for the quadriceps femoris muscle two series of records were obtained for each type of activity (voluntary and reflex) as follows: (1) with one pair of electrodes directly over the anatomical motor point and the other pair four inches distal; and (2) with one pair of electrodes directly over the anatomical motor point and the other pair two inches proximal. Several series of records on several cases were obtained as follows: (1) with one pair of electrodes directly over the motor point and the other pair two inches distal; (2) with one pair of electrodes two inches distal and the other pair four inches distal to the motor point; and (3) one pair of electrodes directly over the motor point and the other pair four inches proximal. The anatomical motor point for the quadriceps femoris muscle group has been determined by Tuttle and MacEwen (5) to be half way between the anterior superior spine of the ilium and the upper margin of the patella. That this is not the physiological motor point will be brought out later.

For the gastrocnemius muscle two series of records were obtained for each type of activity as follows: (1) with one pair of electrodes directly over the motor point and the other pair two inches distal; and (2) with one pair of electrodes directly over the motor point and the other pair four inches distal. For one subject records were obtained with one pair of electrodes two inches distal and the other pair four inches distal to the motor point. The motor point for the gastrocnemius muscle was taken as one-fifth the distance between the lower margin of the patella and a point even with the inferior malleolus. This determination was based upon calculations reported by Hoffman (3).

For each subject a series of voluntary response records followed a series of reflex response records for any given distance apart of the electrodes. The turning of the crank of the photographic unit by the experimenter was the visual signal for as sudden and sharp a voluntary contraction of the muscle as the subject was capable of. This sudden contraction was to follow a relaxed condition in order that the initial action currents might be as clearly defined as possible.

Each series of records recorded from five to eight reflex or voluntary movements. Only the most objective of these records were read. That this selection does not decrease the validity of our results is evident from the factors which destroyed the objectivity of a record. These factors were outside electrical disturbances, disturbances in the muscle not resulting from reflex activity as movement of the fascia or a contraction anticipating the stimulus, absence of or extremely weak jerks, and damage to the film.

Data and Discussion

(*a*) *Rate of the Muscle Contraction Wave in Reflex Activity.*—It may be seen from Table I that the average conduction rates for the quadriceps femoris muscle were 64.3, 62.6, and 57.7 m in a range of 29.7 to 145.1 m per second for different locations of the electrodes. Similarly it may be seen from Table II that the average conduction rates for the gastrocnemius muscle were 49.8, 54.4, and 63.3 m in a range of 38.1 to 94.9 m per second for different locations of the electrodes.

TABLE I

CONDUCTION RATES (METERS PER SECOND) OF THE QUADRICEPS FEMORIS MUSCLE GROUPS DURING REFLEX ACTIVITY

Subject	Position of Second Pair of Electrodes with Respect to Motor Point					
	2″ Proximal		2″ Distal		4″ Distal	
	Mean	Range	Mean	Range	Mean	Range
A	101.6	*–50.8	84.6	101.6–50.8	50.8	50.8–50.8
B					72.6	101.6–67.7
C	50.8	50.8–50.8			50.8	50.8–50.8
D	58.4	101.6–50.8			63.5	67.7–50.8
E					50.8	50.8–50.8
F					39.1	50.8–33.9
G	50.8	50.8–50.8			46.2	50.8–40.6
H					40.6	40.6–40.6
I					67.7	67.7–67.7
J					50.8	50.8–50.8
K					40.6	40.6–40.6
L			50.8	50.8–50.8	63.5	67.7–50.8
M	50.8	50.8–50.8	42.3	101.6–25.4	67.7	101.6–50.8
N	84.6	*–50.8	84.6	101.6–50.8	145.1	*–101.6
O	56.4	101.6–50.8	50.8	50.8–50.8	50.8	50.8–50.8
P	61.2	101.6–50.8			50.8	50.8–50.8
Q					29.7	33.9–29.0
	64.3	*–101.6	62.6	101.6–25.4	57.7	*–101.6

* is used when no difference in latencies appears for different placements of the electrodes.

TABLE II

CLNDUCTION RATES (METERS PER SECOND) OF THE GASTROCNEMIUS MUSCLE DURING REFLEX ACTIVITY

Subject	Position of Second Pair of Electrodes with Respect to Motor Point					
	2″ Distal		3″ Distal		4″ Distal	
	Mean	Range	Mean	Range	Mean	Range
A	58.4	101.6–50.8			81.3	101.6–67.7
B	50.8	50.8–50.8				
C					94.9	101.6–67.7
D	50.8	50.8–50.8			50.8	50.8–50.8
E	38.1	50.8–25.4			58.1	101.6–50.8
F	50.8	50.8–50.8				
G					50.8	50.8–50.8
H			54.4	76.2–50.8	59.8	67.7–50.8
I			54.4	76.2–50.8	50.8	50.8–50.8
J					59.8	67.7–50.8
	49.8	101.6–25.4	54.4	76.2–50.8	63.3	101.6–50.8

The mean for all placements presented in Table I was 59.9 m per second and in Table II 57.6 m per second. According to our records the most frequently occurring conduction rate was between 50 and 65 m per second. Figures 1 and 2 are representative records on which these rates were based.

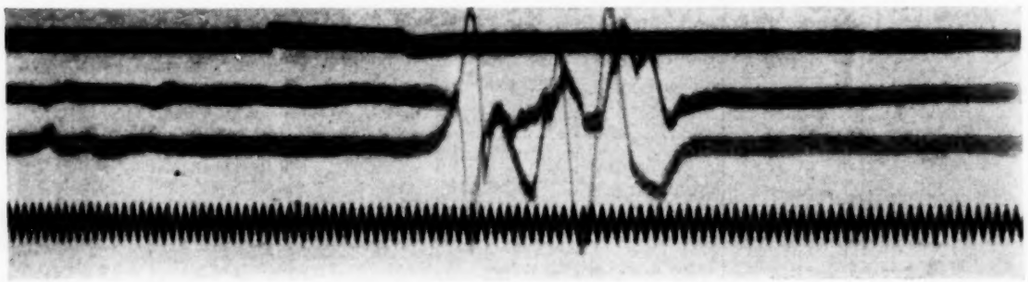

FIG. 1. Typical patellar reflex record. Reading from the top down, the first line recorded the stimulus, the second the action currents from a point four inches distal to the motor point, the third the action currents from the motor point, and the fourth time in sigma. The record was read to give the motor point a shorter latency by two sigma.

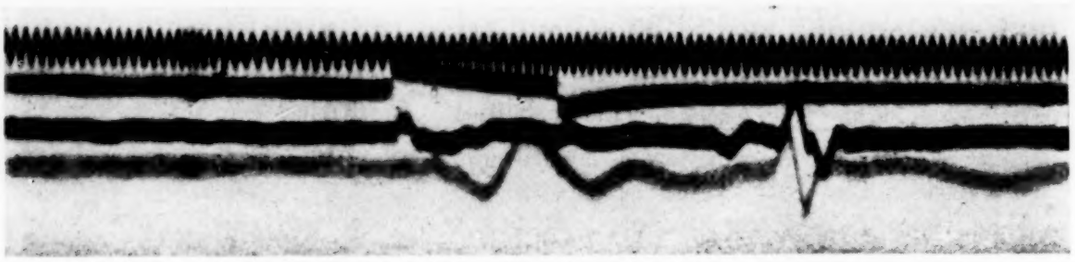

FIG. 2. Typical Achilles reflex record. Reading from the top down, the first line recorded time in sigma, the second the stimulus, the third action currents from a point two inches distal to the motor point, and the fourth the action currents from the motor point. This record was read to give the motor point a shorter latency by one sigma.

The differences in the means for a given individual and the differences in the means for all the subjects for the various placements of the electrodes raised a question as to whether the conduction rate was constant throughout the length of the muscle. The records from a selected group of the subjects would answer the question in the affirmative. For the quadriceps femoris muscle this group included subjects C, D, G, O, and P and for the gastrocnemius muscle, subjects D, H, and I.[1] Each subject in this group was represented by two

[1] On the basis of records taken two inches and four inches distal to the motor point, this group also would include subject B, whose records yielded conduction rates of

or more series of records, the difference between the means of which was not greater than 10 m per second. This difference is the equivalent of not more than half a sigma variation in either direction from the difference in latent times involved in the computation of the means. A half sigma is the extreme variation which can result from a reading error since the time line may be read in units of half a sigma without interpolation. It is very improbable, however, that the difference in means of series resulting from different placements of the electrodes was due to reading errors. A more probable explanation is that either the conduction rate varied within a relatively wide range in a series of muscular contractions or, especially since the greatest deviation was in the direction of simultaneity of appearance of the action currents at two different parts of the muscle (Fig. 3), the branching of the motor nerve was such

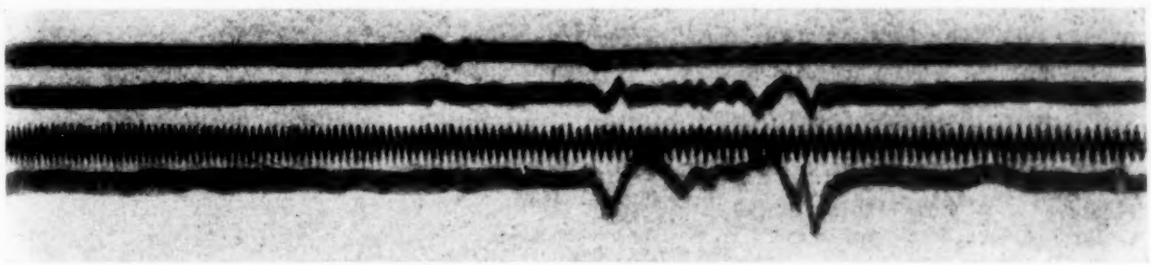

FIG. 3. A patellar reflex record showing simultaneity of appearance of action currents from the motor point and a point four inches distal.

as to innervate two different parts of the muscle practically simultaneously. This latter possibility leads us to believe that the variations noted in the contraction wave rate may not be considered certain evidence against the wave's being propagated throughout the muscle at a constant rate during each individual contraction. Further evidence of a constant rate was that the means for all the subjects for different placements of the electrodes agreed within narrow limits and that this agreement was increased by the greater number of subjects used in determining these means for the quadriceps femoris than for the gastrocnemius muscle.

67.7 and 46.2 m per second for the quadriceps femoris and the gastrocnemius muscles respectively. O's record from the quadriceps femoris at two inches and four inches distal to the motor point was also consistent at 50.8 m per second. A's rate was 50.8 m per second for the quadriceps femoris, which agreed with the mean rate found for A between the motor point and the point 4 inches distal.

TABLE III

COMPARISON OF CONDUCTION RATES (METERS PER SECOND) FOR QUADRICEPS FEMORIS AND GASTROCNEMIUS MUSCLES DURING REFLEX ACTIVITY

Subject	Position of Second Pair of Electrodes with Respect to Motor Point							
	2″ Distal				4″ Distal			
	Quadriceps Femoris		Gastrocnemius		Quadriceps Femoris		Gastrocnemius	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
A	84.6	101.6–50.8	58.4	101.6–50.8	50.8	50.8–50.8	81.3	101.6–67.7
B			50.8	50.8–50.8	72.6	101.6–67.7		
C					50.8	50.8–50.8	94.9	101.6–67.7
D			50.8	50.8–50.8	63.5	67.7–50.8	50.8	50.8–50.8
E			38.1	50.8–25.4	50.8	50.8–50.8	58.1	101.6–50.8
F			50.8	50.8–50.8	39.1	50.8–33.9		
G					46.2	50.8–40.6	50 8	50.8–50.8
H					40.6	40.6–40.6	59.8	67.7–50.8
I					67.7	67.7–67.7	50.8	50.8–50.8
	84.6	101.6–50.8	49.8	101.6–25.4	53.6	101.6–33.9	63.8	101.6–50.8

Comparisons of the conduction rates in the quadriceps femoris and the gastrocnemius muscles are presented in Table III. In general, no striking differences in the conduction rates of the two muscles are to be noted. Variations existed in every case, but in the majority they were not wide nor were they constant in direction from individual to individual. It is certainly not to be expected that every striated muscle in the body contracts at the same rate, but our data indicate similarity rather than difference between the rates of the quadriceps femoris and the gastrocnemius muscles.

(*b*) *The Physiological Motor Point.*—The contraction wave spreads distally and proximally from a point or area in the muscle. This point of origin will be called the physiological motor point. Tuttle and MacEwen's measurement (**5**) of half the distance between the anterior superior spine of the ilium and the upper margin of the patella was used to locate the anatomical motor point of the quadriceps femoris muscle. It was anticipated that the location of the physiological and anatomical motor points would be the same. Our records indicated, however, that the physiological was proximal to this anatomical motor point. Of the records from the quad

riceps femoris muscle with the electrodes placed on the anatomical motor point and two inches proximal of this point, only those from one subject showed the action currents appearing at the motor point before the proximal point (.5 sigma). In the other nine subjects the point two inches proximal gave action currents from .3 to 1.0 sigma (range of the means of the series) before the anatomical motor point. In two of three subjects where the records were taken from the anatomical motor point and a point 4 inches proximal, the proximal point gave action current activity 1.0 and 1.1 sigma (means of the series) before the anatomical motor point. In the third subject the anatomical motor point action currents preceded those from a point 4 inches proximal by .6 sigma (mean of the series) (Fig. 4). In only two subjects,

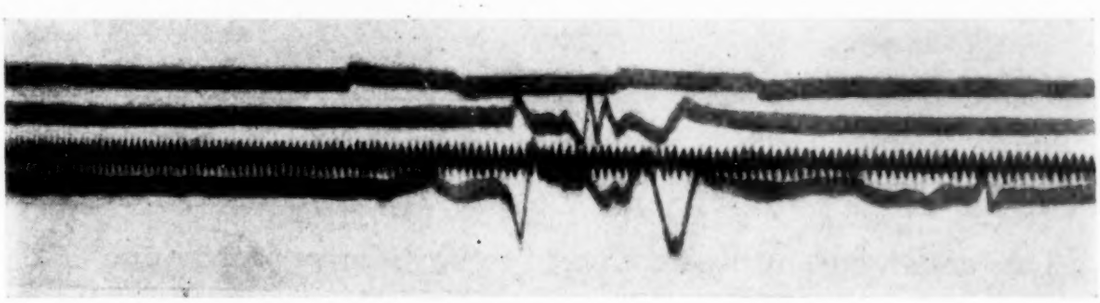

FIG. 4. Patellar reflex record showing spread of contraction from motor point in a proximal direction. Upper action current line records action currents from point four inches proximal to motor point; lower action current line from the motor point. Record was read to give the point four inches proximal a longer latency by one-half sigma. It will be noted that there is a one hundred and eighty degree difference in phase in the initial action current waves of this record. This difference is to be expected if the electrodes are placed upon the muscle so that a unidirectional wave of contraction produces no difference in phase and this unidirectional wave is replaced by a wave moving in opposite directions from a point of origin located between the two pairs of electrodes.

therefore, have we evidence that the physiological motor point was located within a radius of two inches of the anatomical motor point; in eleven cases our records showed that the physiological motor point must have been located more than two inches proximal to the anatomical motor point as determined by Tuttle and MacEwen. Our results support Golla and Antonovitch's findings in regard to the location of the physiological motor point (**4**). They reported for one subject

a motor point one-third the distance between the anterior superior spine of the ilium and the insertion of the muscle (upper margin of the patella). Since we were not successful in obtaining records proximal to the selected anatomical motor point of the gastrocnemius muscle, no conclusion concerning the physiological motor point of this muscle may be drawn.

(*c*) *Direction of Muscle Contraction Wave in Reflex Activity.*—Almost all of our records from points both proximal and distal to the anatomical motor point showed the contraction wave moving down the muscle from a proximal to a distal point (Figs. 1 and 2). In two subjects the action currents from the anatomical motor point preceded those from the proximal points. Here we have evidence of the contraction wave spreading in a proximal direction (Fig. 4).

(*d*) *Nature of the Contraction Wave in Reflex Activity.*—The contraction wave in reflex activity is a transient phenomenon accompanied or preceded by characteristic diphasic action current responses. A striking similarity was evident in the simultaneous records from two points on the muscle. One action current line appeared to be an imperfect reproduction of the other. The difference in time that existed between the first action current waves from the two points on the muscle was seldom maintained constantly throughout the remainder of the record (Fig. 5). A difference in the refac-

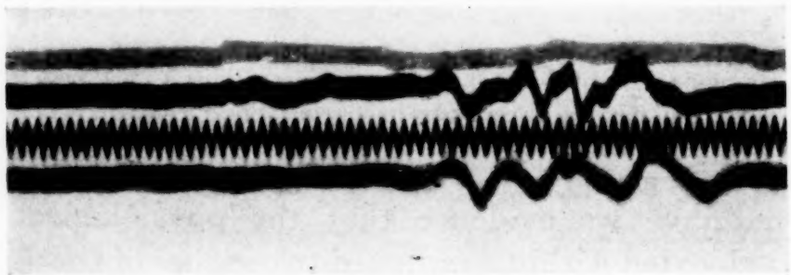

FIG. 5. Patellar reflex record showing approximate similarity of the two action current records from different points on the muscle. Upper action current line records action currents from point two inches proximal; lower from the motor point.

tory periods at the two points in the muscle may account for this failure to maintain a constant time relationship between successive action current waves.

Each contraction wave in a series of reflex movements was represented by a pattern characteristic of the series as a whole. This similarity between different records in a series was so marked that records might be recognized as belonging to a particular series. The contraction wave in reflex activity appears, therefore, to be a regular phenomenon in spite of the fact that its rate of conduction may vary.

(*e*) *Rate of Muscle Contraction Wave in Voluntary Activity.*—The records of voluntary activity presented difficulties in reading that made the computation of the rate of the contraction wave very difficult (Fig. 6). In voluntary activity the

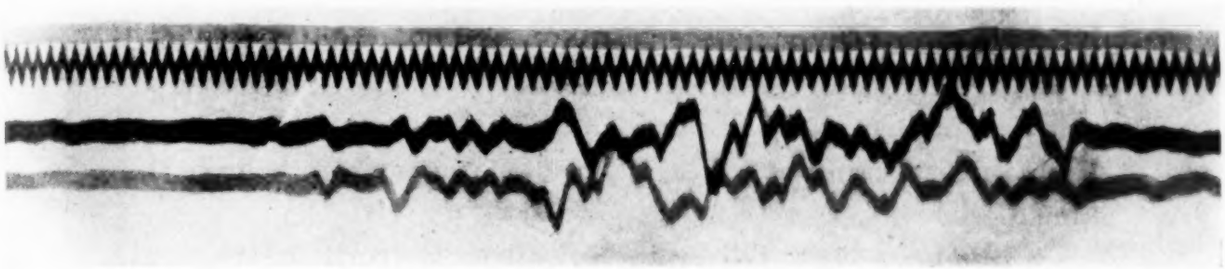

FIG. 6. Record of voluntary contraction of quadriceps femoris muscle that was judged unreadable. Upper action current line records action currents from point four inches distal; lower from the motor point.

contraction was often represented by initial action current waves of very small amplitude and uncertain beginning. Any contraction of the muscle or increase in tonus in anticipation of the signal for movement was probably also represented by small action current waves; a long series of small action current waves in a record may be indicative of this anticipatory contraction.

We were able to obtain, however, a few objective and conclusive records during voluntary activity. From these we found the mean velocity of the contraction wave to approximate that in reflex activity. However there was a greater variability in conduction rate in voluntary than in reflex movement.

(*f*) *Direction of Contraction Wave in Voluntary Activity.*—Certain of our records presented contradictory evidence concerning the direction of the contraction wave in voluntary activity. Records from the same individual and in the same

series showed a reversal of direction of conduction from that which appeared to be established by other records of the series. In general, however, the direction was the same as was found in reflex activity.

(*g*) *Nature of Contraction Wave in Voluntary Activity.*—In voluntary activity the action currents were of greater duration than in reflex activity and they presented a pattern which was in marked contrast to the stereotyped pattern in reflex contractions. An increase in amplitude of the action current waves to a maximum and a subsequent decrease to a minimum and the similarity of the action current patterns from two different points on the muscle were characteristic (Fig. 7). The close agreement of the two action current patterns is indicative of the existence of a true contraction wave and refutes the argument that the action currents are representative of only random activity at the points from which they are taken.

Summary.—(1) This paper reports a study of the rate, direction, and nature of the muscle contraction wave in reflex and voluntary activity. The action current technique was utilized.

(2) The average conduction rate for the quadriceps femoris muscle in reflex activity was 59.9 m in a range of 29.7 to 145.1 m per second. The average conduction rate for the gastrocnemius muscle in reflex activity was 57.6 m in a range of 38.1 to 94.9 m per second. Although the conduction rate for these two muscles in voluntary activity varied through a wide range it tended to approximate that in reflex activity.

(3) In general, the direction of the contraction wave in the quadriceps femoris and the gastrocnemius muscles during reflex and voluntary activity was from proximal to distal. In the quadriceps femoris muscle the contraction wave in reflex activity moved away in opposite directions from a certain point or area in the muscle. This point of origin was designated the physiological motor point.

(4) The physiological motor point was found to be located proximal to the anatomical motor point situated, according to the measurements of Tuttle and MacEwen, half way be-

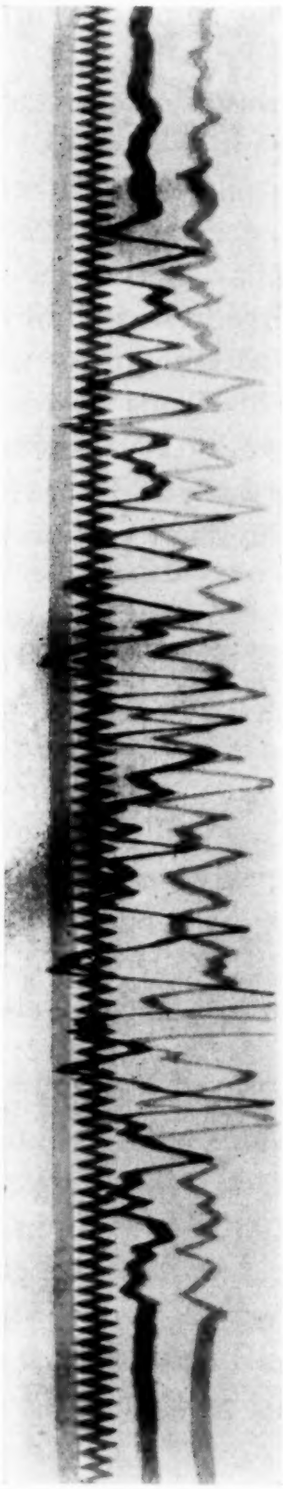

FIG. 7. Readable record of voluntary contraction of gastrocnemius muscle. Upper action current line records action currents from point four inches distal; lower from motor point. Record was read to give the motor point a shorter latency by one and one-half sigma.

tween the anterior superior spine of the ilium and the upper margin of the patella.

(5) The contraction wave in reflex activity was different from the contraction wave in voluntary activity in its brevity and in a more striking similarity between individual records of a given series. The contraction wave in reflex and in voluntary activity were similar in the imperfect duplication of the pattern of action current waves from one point on the muscle by the pattern of action current waves from any other point on the muscle. This leads us to believe that muscle action currents in either voluntary or reflex action are indicative of a true contraction wave and not representative of only random activity of single units at various points in the muscle.

References

1. Adrian, E. D., Oliver-Sharpey lectures on the interpretation of the electromyogram, *The Lancet*, 1925, **208**, 1229–1233.
2. Dodge, R., A systematic exploration of a normal knee-jerk, its technique, the form of muscle contraction, its latent time, and its theory, *Zeit. F. allg. Physiol.*, 1911, **12**, 1–58.
3. Hoffmann, F. A., Zur Kenntnis des Achillessehnenreflexes, *Deutsch. Arch. f. Klin. Med.*, 1918, **126**, 318–326.
4. Golla, F. and Antonovitch, S., The rate of conduction in the human motor nerve, *Brain*, 1931, **54**, 492–507.
5. Tuttle, W. W., and MacEwen, E. M., A method of determining the length of the femoral nerve and for locating the motor point of the rectus femoris muscle in the intact human body, *Anat. Rec.*, 1928, **37**, 317–319.

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THE WEBER–FECHNER LAW AND MENTAL MEASUREMENT

BY F. M. URBAN

L. L. Thurstone [1] tested the validity of Fechner's Law for certain stimuli by the method of equal appearing stimuli. I discussed his data at some length and showed that they yield much better results if treated by purely statistical methods. My papers are rather technical and contain much detail with which one must be familiar in order to follow easily the course of reasoning. I like to present the argument in such a way that the reader might judge its value without going into technical details. The reader is asked to take my statements as to the results of the calculation at their face value and to judge the argument independently. Correctness of the numerical results is very important, nay indispensable, but these results are merely a link in a long chain of reasoning. Testing the other links and their interconnection is a task of sufficient interest and difficulty, since the problems discussed in this paper belong to the most disputed in psychology.

Thurstone experimented with a series of 96 cards on which squares of equal size were printed. The squares were filled with irregularly spaced dots and their number was the stimulus experimented upon. The smallest number of dots in a square was 68, the largest 198. Between these limits 22 steps were inserted, the numbers of dots increasing approximately as the terms of a geometric series. There were 24 stimuli in all, each one represented by four cards.

The subject was required to sort the cards into ten groups which in regard to the density of dots seemed to be equally different. 101 subjects were experimented upon, so that 404 experiments were made with each one of the 24 stimuli.

Table 1 shows the number of times each stimulus was

[1] L. L. Thurstone, Fechner's law and the method of equal appearing intervals, *Journal of Experimental Psychology*, 1929, 12, 214–224.

TABLE I

Stimulus	1	2	3	4	5	6	7	8	9	10
68	246	85	38	27	4	3			1	
71	147	123	77	40	12	2	1		2	
74	169	112	66	42	12	2	1			
77	72	140	103	53	20	12	3	1		
81	51	122	126	51	34	13	5	1	1	
84	55	113	120	58	40	12	3	3		
89	13	59	126	104	56	34	8	4		
93	14	54	106	92	69	39	20	7	3	
97	8	53	89	104	95	40	11	2	2	
102	1	30	59	102	119	52	32	9		
107	7	26	73	92	115	49	34	8		
112	1	21	26	73	119	75	68	16	5	
117		9	26	57	90	79	97	36	10	
123		6	11	34	84	118	89	47	15	
129		3	15	34	71	88	113	58	21	1
135		4	14	39	59	107	101	63	17	
142		2	4	15	28	73	122	92	64	4
149				6	25	58	112	122	69	12
156			5	8	15	36	89	117	104	30
164			1	3	14	27	61	127	123	48
172			1	6	13	21	43	108	143	69
180			1	2	3	14	23	76	154	131
189				2	1	9	14	40	116	222
198					1	1	6	16	83	297
Sum	784	962	1087	1044	1099	964	1056	953	933	814

assigned to a certain group. The first column gives the stimuli, that is the number of dots in the square. The other columns are marked with the numbers 1 to 10, referring to the 10 groups into which the subject sorted the cards. The table shows *e.g.* that the card with 68 dots was assigned to the first group in 246 cases, and that the card with 84 dots was assigned in 58 cases to the fourth group. The sum of the numbers on one line must be 404, since this is the number of experiments performed with every stimulus.

Thurstone says that mere inspection of this table shows that the distribution of these numbers can not be normal, since the results accumulate at the ends of the table. The accumulation is very evident indeed in the upper left and lower right hand corner of the table, but the numbers in the central lines and columns show almost normal distributions. A closer scrutiny of these figures very likely will reveal the well-known small deviations from the normal which one finds in almost every empirical array, even if the sample is taken

from a population about the normal distribution of which there is no doubt. There is no marked asymmetry in the lines 102, 107, 112, 117, 123, 129, 135, and columns 5, 6, 7, and the symmetry of these distributions may be predicated with great confidence.

There is no question as to the asymmetry of the distributions in the other lines and columns: The figures break off suddenly at one side and gradually fall off at the other. A closer scrutiny suggests the following view. The figures look, as if one had to deal with parts of normal distributions, *i.e.* with symmetrical distributions cut off at the upper or lower end. The numbers in the lines 68, 71, 189, 198 may be regarded as distributions of extreme asymmetry, corresponding rather closely to certain Pearsonian curves. It is much harder to take this view in regard to the distributions 77, 81, 164, 180, since the figures increase and decrease gradually, only to break off suddenly at one side of the maximum. This sudden breaking off is still more pronounced for the other observations and no Pearsonian curve can represent them without bias. All the data, however, are in perfect agreement with the view that we have to deal with normal distributions cut off at one end.

Let us imagine that Table 1 is part of a larger table the additional data of which make all the distributions in Table 1 complete and normal. Table 1 is cut out from this larger table. It would not be difficult to formulate this supposition in an abstract way, but the idea is sufficiently clear not to need further elucidation. The idea of this larger table is not far-fetched and seems to come to everybody who pays close attention to these data: Thurstone had it, when he speaks of the possibility that a card might be sorted into the 12, or 15, group.

The idea of this larger table is useful and makes the results plastic, but it is not indispensable for our further discussion. The assumption that the figures in the ten columns represent normal distributions cut off at one end, is essential in so far as it enables us to use the method of constant stimuli, as will be seen later. This is a labor-saving device. Theoretically

the problem may be solved under the most general assumption, but the solution requires much more work. The treatment of Thurstone's data requires an unusual effort anyhow and it is advisable to simplify the work as much as possible, for otherwise it might exceed the strength of the individual worker.

The data of Table 1 may be treated by a process which is nothing else but the method of constant stimuli adapted for this particular case. I described this method in a paper which came out in 1915.[2] Thurstone did not notice that this method applies to his data and we will work them out in this way.

Table 1 may be resolved in a series of tables for the method of constant stimuli, each table referring to a different standard. Let us consider *e.g.* the data in column 5. In these experiments the subjects judged the comparison stimuli 68, 71, 74, . . . as equal to the standard 5. This standard is defined introspectively as the requirements which a stimulus has to fulfill in order to be assigned to the fifth group. The objective value of this standard is unknown and must be determined in the same way in which the intensity corresponding to the standard stimulus is found in the method of constant stimuli. This is done by the formula for the point of subjective equality.

The cases in which the stimuli were assigned to the groups 6, 7, 8, 9, 10 correspond to the 'greater' judgments in regard to the standard 5, since sorting a card into the sixth or a higher group is equivalent to the statement that the stimulus produced an impression which was stronger than to justify its assignment to the fifth group. In the same way: Sorting a card into one of the groups 1, 2, 3, 4 is equivalent to a 'smaller' judgment with reference to the standard 5.

This is a logical construction which does not intend to obliterate the psychological difference between the groupings in the method of equal appearing intervals and the ordinary comparison judgments in the method of constant stimuli. Comparison and standard stimulus are directly and objec-

[2] F. M. Urban, Ueber Grössenschätzungen in objektiven Massen, *Archiv. f. d. ges. Psychologie*, 1915, Bd. 33, pp. 274–291.

tively given in the latter experiments only, while in the former the standard is given indirectly by the requirements which the subjects sets up in a rather obscure way. The investigation of the process by which the subject sets up the standards for the different groups is a difficult introspective problem, which has not yet been investigated.

Sorting a stimulus into one of the ten groups is logically equivalent to a judgment, although it has not the form of one. Any experimenter who has used the method of constant stimuli will have noticed the influence of apparently small changes in the form of the judgment on the relative frequencies of the different categories. It is not at all certain that the relative frequencies of the categories will remain unchanged, if oral expression of the judgment is substituted to the sorting of cards. The form of expressing the judgment may be of influence on the judgment itself, and the direct comparison of the stimuli is different from the mental process in the method of equal appearing intervals. It is much more involved in the latter experiments. There is, at present, very little introspective evidence at hand about the process by which we assign a stimulus to a certain group and it is highly desirable that some competent person should undertake an introspective analysis of the experiments in the method of equal appearing intervals.

Sorting a card into group 5 is equivalent to the statement that the stimulus satisfies the requirements which justify its assignment to this group. This means that the stimulus is too strong to be sorted into one of the groups 1–4, and too small to be sorted into one of the groups 6–10. The same holds true for all the other groups. This means that Table 1 may be resolved in a number of tables with the categories 'smaller,' 'equal,' 'greater' giving the frequencies of these judgments for the standards 1 to 10. These tables are exactly of the kind needed for the method of constant stimuli and we may draw all the advantages from this fact. The first step consists in changing the absolute frequencies into relative frequencies. This is done in Table 2.

We now have to set up the frequency tables for the method

TABLE 2

Stimulus	1	2	3	4	5	6	7	8	9	10
68	0.61	0 21	0.09	0.07	0.01	0.01				
71	0.37	0.31	0.19	0.10	0.03					
74	0.42	0.28	0.16	0.10	0.03					
77	0.18	0.35	0.26	0.13	0.05	0.03	0.01			
81	0.13	0.30	0.31	0.13	0.08	0.03	0.01			
84	0.14	0.28	0.30	0.14	0.10	0.03	0.01	0.01		
89	0.03	0.15	0.31	0.26	0.14	0.08	0.02	0.01		
93	0.03	0.13	0.26	0.23	0.17	0.10	0.05	0.02	0.01	
97	0.02	0.13	0.22	0.26	0.24	0.10	0.03			
102		0.07	0.15	0.25	0.30	0.13	0 08	0.02		
107	0.02	0.06	0.18	0.23	0.29	0.12	0.08	0.02		
112		0.05	0.06	0.18	0.30	0.19	0.17	0.04	0.01	
117		0.02	0.06	0.14	0.22	0.20	0.24	0.09	0.02	
123		0.01	0.03	0.08	0.21	0.29	0.22	0.12	0.04	
129		0.01	0.04	0.08	0.18	0.22	0.28	0.14	0.05	
135		0.01	0.03	0.10	0.15	0.27	0.25	0.16	0.04	
142			0.01	0.04	0.07	0.18	0.30	0.23	0.16	0.01
149				0.01	0.06	0.14	0.28	0.30	0.17	0.03
156			0.01	0.02	0.04	0.09	0.22	0.29	0.26	0.07
164				0.01	0.03	0.07	0.15	0.32	0.31	0.12
172				0.01	0.03	0.05	0.11	0.27	0.36	0.17
180					0.01	0.03	0.06	0.19	0.38	0.33
189						0.02	0.03	0.10	0.29	0.55
198							0.01	0.04	0.21	0.74

of constant stimuli. Let us take as an example the data for the standard 2. The column 'equal' gives the relative frequency of the cases in which the stimuli were judged equal to standard 2. The column 'smaller' gives the relative frequencies of the cases in which the stimulus was assigned to group 1, *i.e.* was judged smaller than standard 2. The column 'greater' gives the relative frequencies of the cases in which the stimulus was sorted into one of the groups 3–10, *i.e.* was judged greater than standard 2. The latter figures are obtained by adding in Table 2 all the numbers in a line at the right of the column 2.

It looks as if such a table would have to be printed for everyone of the standards 1–9, and this would be a cumbersome affair. Fortunately one may take advantage of a peculiarity of the data in order to get along with one single table. Let us form in Table 3 the sums of the number, in the columns 'smaller' and 'equal.' These sums are by definition the frequencies of the 'smaller' judgments for standard 3. The numbers on a line in Table 3 add up to unity, from which

it follows that the psychometric function of the 'smaller' judgments for standard 3 is obtained by subtracting from unity the psychometric function of the 'greater' judgments for standard 2.

TABLE 3

RELATIVE FREQUENCIES OF THE JUDGMENTS. STANDARD 2

Comparison Stimulus	Smaller	Equal	Greater
68	0.61	0.21	0.18
71	0.37	0.31	0.32
74	0.42	0.28	0.30
77	0.18	0.35	0.47
81	0.13	0.30	0.57
84	0.14	0.28	0.58
89	0.03	0.15	0.82
93	0.03	0.13	0.84
97	0.02	0.13	0.85
102		0.07	0.93
107	0.02	0.06	0.92
112		0.05	0.95
117		0.02	0.98
123		0.01	0.99
129		0.01	0.99
135		0.01	0.99

These sums are given in Table 4. The figures in the first column are identical with those in column 1 of Table 2. Col-

TABLE 4

	1	2	3	4	5	6	7	8	9
68	0.61	0.82	0.91	0.98	0.99	1.00	1.00	1.00	1.00
71	0.37	0.68	0.87	0.97	1.00	1.00	1.00	1.00	1.00
74	0.42	0.70	0.86	0.96	1.00	1.00	1.00	1.00	1.00
77	0.18	0.53	0.79	0.92	0.97	0.99	1.00	1.00	1.00
81	0.13	0.43	0.74	0.87	0.95	0.98	1.00	1.00	1.00
84	0.14	0.42	0.72	0.86	0.96	0.99	1.00	1.00	1.00
89	0.03	0.18	0.49	0.75	0.89	0.97	0.99	1.00	1.00
93	0.03	0.16	0.42	0.65	0.82	0.92	0.97	0.99	1.00
97	0.02	0.15	0.37	0.63	0.87	0.97	1.00	1.00	1.00
102		0.07	0.22	0.47	0.77	0.90	0.98	1.00	1.00
107	0.02	0.08	0.26	0.49	0.78	0.90	0.98	1.00	1.00
112		0.05	0.11	0.29	0.59	0.78	0.95	0.99	1.00
117		0.02	0.08	0.22	0.44	0.64	0.88	0.97	0.99
123		0.01	0.04	0.12	0.33	0.62	0.84	0.96	1.00
129		0.01	0.05	0.13	0.31	0.53	0.81	0.95	1.00
135		0.01	0.04	0.14	0.29	0.56	0.81	0.97	1.00
142			0.01	0.05	0.12	0.30	0.60	0.83	0.99
149				0.01	0.07	0.21	0.49	0.79	0.98
156			0.01	0.03	0.07	0.16	0.38	0.67	0.93
164				0.01	0.04	0.11	0.26	0.58	0.89
172				0.01	0.04	0.09	0.20	0.47	0.83
180					0.01	0.04	0.10	0.29	0.67
189						0.02	0.05	0.15	0.44
198							0.01	0.05	0.26

umn 2 gives the sums of the numbers in the first two columns of Table 2; column 3 gives the sums of the figures in the first 3 columns of Table 2; and so on to the ninth column. Column 10 is omitted, since the sum of all the figures in one line of Table 2 must be equal to unity. The figures of column 9 may be obtained by subtracting from unity the corresponding figures in column 10 of Table 2.

It is an obvious idea to adjust these data by the $\Phi(\gamma)$—hypothesis. The general course of the figures closely resembles that of the psychometric functions of the 'smaller' judgments. It would not be surprising if a more detailed investigation showed the well known small deviations, but this hypothesis does excellent service as a first approximation. The constant process recommends itself by its simplicity. The relation between the psychometric functions of consecutive standards, which was mentioned in explaining Table 4, reduces the work by exactly 50 percent.

The relative frequency of the 'greater' judgments for the standard i and the relative frequency of the 'smaller' judgements for the standard $i + 1$ add up to unity. The values of γ are equal in both sets of equations and corresponding equations have the same weight. The observation equations for the constant, of the psychometric functions of the 'greater' judgments for the standard i are identical with those for the constants of the psychometric functions of the 'smaller' judgments for the standard $i + 1$. The following proposition holds true for every standard. The constants of the psychometric functions of the 'greater' judgments are equal to those of the psychometric functions of the 'smaller' judgments for the next higher standard. It is sufficient to do the work for the 'greater' judgments in order to obtain the complete adjustment of the data in Table 4.

The observation equations are set up in the usual way. The details are found on p. 303 of my paper 'Ueber die Methode der gleichen Abstufungen.'

It is important to make the following remark. The work in setting up the normal equations is hard, because the stimuli are not equidistant which prevents the use of my tables for

the method constant stimuli. This is a great inconvenience for the computer who has to do the work. It is, however, not more than an inconvenience, since the result is found without the possibility of an error creeping in, if one follows the scheme outlined in my paper on psychophysical methods of 1909.

The investigator who devises and makes experiments must consider the wishes of the computer as far as possible, but they never must be decisive in planning the experiments. The quality of the experiments must be the first consideration. Thurstone explains the reasons, why he decided against equidistant stimuli and one must fully approve of his decision. Had the comparison stimuli been equidistant, the last group very likely would have contained very many cards and the subject might have been disturbed by the fact that the groups kept on increasing.

The solution of the normal equation gave the following results:

TABLE 5

Standard	h	S_1	S_2	$S_2 - S_1$	ξ
1	0.0506		68.32		
2	0.0391	68.32	79.39	11.07	73.74
3	0.0353	79.39	92.07	12.68	85.40
4	0.0320	92.07	104.65	12.58	98.05
5	0.0297	104.65	118.74	14.09	111.27
6	0.0283	118.74	131.47	12.73	124.95
7	0.0293	131.47	149.17	17.70	140.30
8	0.0295	149.17	166.86	17.69	157.88
9	0.0352	166.86	187.31	20.45	177.99
10	0.0352	187.31			

There are no data for determining the lower limit of the interval of uncertainty for standard 1, and the upper limit for standard 10. The interval of uncertainty for standard i is defined as the interval of the stimuli, in which the 'smaller' judgments as well as the 'greater' judgments have probabilities not exceeding 1/2. Outside of this interval the probabilities either of the 'smaller' judgments or of the 'greater' judgments exceed the value 1/2. The length of this interval gives an indication as to the precision with which the standard i is perceived. The interval of uncertainty plays the

same part in these experiments as in ordinary psychophysical work.

The interval of uncertainty does not vary regularly with the standard. These intervals are large and the values of h are small, what indicates that the standards are not very clearly defined. One might have guessed this fact from the relative frequencies of the equality judgments in Table 2. There are 169 values listed, but only three of them are greater than 1/2. In so far as the equality judgments are concerned Thurstone's data resemble those of my experiments on lifted weights in which the psychometric function of the equality judgments never reached the value 1/2.

The data given above furnish the material for discussing the so-called Weber-Fechner Law. If one abstracts from the fact that the data were obtained in a group experiment, Thurstone's results are probably the best material available at present for such a discussion.

The Weber-Fechner Law is the object of an immense literature and it would be a somewhat useless undertaking to review all the opinions advanced on this topic. Before entering into the discussion of Thurstone's data and their bearing on this law, we will make some statements which escaped until now the attention of the investigators. They are rather obvious to anyone familiar with the statistical character of modern psychophysics, but they will help to settle many questions of fact. Among the questions to which we offer a definite answer, some of the most baffling problems of psychology are found.

Weber's Law predicates the constancy of the relative threshold. By this one usually understands the ratio of the threshold of difference to the standard stimulus. On account of the constant errors the standard stimulus is not suited as point of reference. It seems obvious that the ratio of the interval of uncertainty to the point of subjective equality is the only value to which some such statement as Weber's Law may be referred. These values are given below in the third column under the heading $\frac{S_2 - S_1}{\xi}$.

Fechner's Law claims that sensation increases as the logarithm of the stimulus. Fechner derives this proposition as a consequence of Weber's Law and these two propositions are logically equivalent, if there is no mistake in Fechner's deduction. The statement that the laws of Fechner and of Weber are different propositions may seem superfluous, but is important nevertheless.

It is hard, not to say impossible, to connect a definite meaning with Fechner's proposition, since his equation connects quantities of different dimensions, putting a sensation equal to a physical quantity. One might say that this equality is produced by the constant in Fechner's differential equation, but this argument merely hides the difficulty without removing it, since we can not conceive of any constant producing equality between physical and psychical entities.

Avoiding all theoretical considerations we pronounce Fechner's proposition in a form, in which it has a definite meaning and in which it might be tested by experience: *The estimation value*, i.e. *the point of subjective equality increases as the logarithm of the stimulus.* This proposition implies that the ratio of equidistant estimation values must be constant. These ratios are given in the column $\xi_i : \xi_{i-1}$.

TABLE 6

THE POINT OF SUBJECTIVE EQUALITY AND RELATIVE THRESHOLDS

Standard	$\xi_i : \xi_{i-1}$	$\frac{S_2 - S_1}{\xi}$
2	—	0.151
3	1.168	0.148
4	1.148	0.128
5	1.135	0.127
6	1.123	0.102
7	1.123	0.126
8	1.125	0.112
9	1.127	0.115

The figures in the last column do not agree well with Weber's Law. The difference between the largest and the smallest value is almost exactly 50 percent of the latter and one must be very modest in one's demands on accuracy of statistical results, if one speaks of the constancy of the relative threshold in Thurstone's experiments.

The second column gives the values $\xi_i : \xi_{i-1}$, *i.e.* the ratio of the estimation values of consecutive standards. These figures vary between 1.123 and 1.168 and the smallest value differs from the largest by not more than 4 percent of the latter. This agreement is all the more remarkable, since the precision of the determination of ξ is not very high and one will not find easily another statistical regularity referring to such complicated facts, which is fullfilled with equal accuracy.

Fechner very likely would have taken this result as a splendid proof for the correctness of his law, which follows directly from this result, if the standards are equidistant. This assumption is hard to defend. It is true that the differences between the standards seem to be equal, but it is arbitrary to represent them by equidistant points on the abscissa. Without settling this point the method of equal appearing intervals can not furnish a real proof of Fechner's logarithmic law. At the best—if the results are as unambiguous as in Thurstone's experiments—one may venture the following formulation: *If a stimulus interval is divided into a number of steps, which the subject perceives as equal, the estimation values of consecutive steps are in constant ratio.*

We must call attention to the remarkable fact that Fechner's law is verified excellently, and Weber's law rather poorly in the experiments under discussion. This suggests the view that there exists no connection between these propositions and, should it exist, it must be very loose. It is unlikely that one of the propositions should be logically dependent on the other, as Fechner's deduction of his law implies, for a given material should fit two equivalent propositions equally well. It will be interesting to continue the observation on this point, keeping in mind that the laws of Weber and of Fechner are different propositions. Perhaps some material may be found in which Fechner's Law is verified poorly and Weber's Law well.

The statistical conception of psychophysics removes the last trace of mystery surrounding Fechner's Law. A statement about the increase of the estimation value of the standard stimulus is perfectly plain and straightforward, for it

connects quantities of the same kind and dimension. The logarithmic law differs from other similar statements merely by the surprising accuracy with which it is verified in Thurstone's experiments. It states a relation of medium, but by no means excessive complication between the constants of the psychometric functions for different standards. It stands at about the same level as the well-known proposition that the point of subjective equality divides the interval of uncertainty in the relation $h_2 : h_1$.

This matter-of-fact view has, perhaps, the disadvantage not to appeal as strongly to the imagination as Fechner's view. The logarithmic law seemed to establish a relation between physical and psychical quantities, and the mere existence of one such relation suggested the possibility that other, similar propositions may be found. The immense energy with which investigators of the whole world took up the study of psychology presumably was due to the exaggerated hopes and expectations aroused by Fechner's Law. This proposition found its correct place and formulation in the system of statistical psychophysics, but one may doubt whether psychology had advanced as rapidly as it did, had Fechner begun his system with a prosaic statement about the constants of the psychometric function.

We explained the difficulty of proving the logarithmic law by the method of equal appearing intervals. Which experimental material is best suited for this purpose? The answer is easy, although it is very hard to procure the necessary data: We must experiment with different standards and procure for each of them a complete series for the method of constant stimuli. We calculate from these results the interval of uncertainty and the point of subjective equality for every standard and test on these figures Weber's law as well as that of Fechner. Both these quantities depend on the constants h_1, c_1, h_2, c_2 and one sees at once that the laws of Weber and of Fechner are statements about the constants of the psychometric functions for different standard stimuli.

Let us consider a particular example in order to explain the character of such an investigation. We experiment with

lifted weights, standard weight first, avoiding the space error, and determine the psychometric function of the 'smaller' judgments. The standards are 70, 80, 90, 100, 110, 120 grs, each one of which is compared with a suitably chosen series of comparison weights. The data obtained enable us to determine the psychometric functions for all the standards.

Let us draw the curves representing for all the standards the psychometric functions of the 'smaller' judgments on sheets of paper on the same scale and cut them out. We then place these figures in vertical position at equal distances on a horizontal plane. The curves outline a surface which sets in on the left side with values close to unity and falls off at first slowly, then more rapidly, and eventually with ever diminishing rapidity towards the horizontal which marks the value zero. The curves are the intersection of this surface with vertical planes constructed at the distances 70, 80, . . . 120. The surface represents the probabilities of the 'smaller' judgment as dependent on the intensities of the comparison— and the standard stimulus.

We may represent the dependence of the probabilities of the 'greater' and 'equal' judgment on the two stimuli in the same way. The probabilities of the 'greater' judgments are represented by a surface gradually rising towards the right and approaching the value 1 asymptotically. The curve representing the psychometric function for a given standard stimulus is given by the intersection of this surface with a vertical plane at the given distance.

The probabilities of the equality judgments are represented by a kind of hill or ridge extending roughly in the direction of the Y-axis. The intersection of this surface with vertical planes gives the psychometric function of the equality judgments for the corresponding standard stimulus.

There are several ways of indicating the course of these surfaces. The most direct way consists in giving the cross-sections of the surface with a number of vertical planes. Another method consists in constructing the level-lines. Both methods are laborious and yield results which in one respect at least are unsatisfactory. The probabilities of the different

judgments are determined from the observed relative frequencies, which are affected by the unavoidable errors of observation. It seems illogical to waste a great deal of work merely for preserving data of which one is sure that they can not be absolutely correct.

The best solution is found in the following way. The surfaces represent the psychometric function and are given by certain analytic expressions, differing according to the conditions of the experiments and the psychophysical constitution of the subject. These expressions contain a certain number of constants which must be determined from the data of observation. Were these expressions known, the determination of the constants would not offer any great difficulty. In fact it is a problem well known from the method of constant stimuli. The question merely is how to find these expressions. It will be shown that no new hypothesis has to be made and that the problem is solved by a perfectly natural generalization of the method of constant stimuli.

Let us draw in the horizontal plane a line parallel to the abscissa at the distance s. A vertical plane through this line will intersect the surface in a certain curve representing the psychometric function for the standard s, first time order, standard first. Now let us draw in the distance s a line parallel to the ordinate and lay a vertical plane through this line. This plane will intersect the surface in a curve representing the psychometric function for the second time order, standard second. The probabilities refer to experiments in which a variable weight is lifted first and compared with a constant weight, lifted second.

It is customary to use the method of constant stimuli for experiments in the second time order as well as for those in the first. The $\Phi(\gamma)$ hypothesis represents the psychometric functions for both time-orders and this means that we know the form of the surface along intersections parallel to the abscissa as well as to the ordinate. This enables us to determine the general formula of this surface.

The problem is solved by calculations similar to those in the method of constant stimuli. There is just one small

difference: We have four unknown quantities, instead of two. The work is not exactly difficult, but rather involved so that some care is needed to lead the computation to a successful end. The theory of the whole process and the convenient arrangement of the computation is explained in a separate paper.[3]

Let us return to Table 4 and look at it in the light of the preceding considerations. It is a table of double entry, the first referring to the stimulus, the second to the intermediate steps accessible to the introspections of the subject only. The numbers 1, 2, . . . 10, by which we designate these steps, are ordinal numbers and instead of them we might just as well use the letters *a*, *b*, . . . *j*. The constants of the psychometric functions for these standards are given above and these results are independent of the supposition that the manifold of the intermediate steps is measurable. The correctness of this statement is seen from the fact that the intensity of the standard stimulus does not enter the calculations of the method of constant stimuli.

Here is the psychic manifold of the intermediate steps and we want to treat the question of its measurability as a question of fact: What consequences do we obtain by treating this manifold as measurable? Its measurability is a hypothesis which we want to test by its consequences. The method of testing this hypothesis is straightforward: The data obtained under the assumption of the measurability of this psychic manifold must be compared to those found independently of this hypothesis. If the agreement between the results obtained by the two methods is sufficiently close we will conclude that experience does not contradict the assumption of the measurability of psychic manifolds. The chance to approach this problem by experimental methods must not be missed.[4]

[3] F. M. Urban, Die Verallgemeinerung der Konstanzmethode, *Archiv. f. d. ges. Psychologie*, 1931, **80**, pp. 167–178. The method of constant stimuli lends itself to many, very varied generalizations and some of my former publications deal with the same topic. I like to call attention to a mistake in the table on p. 174. The figures for *P* are not correct. The further data from p. 176 onward are based on the correct values and this mistake has no influence on the final result.

[4] F. M. Urban, Die Messbarkeit psychischer Mannigfaltigkeiten, *Archiv f. d. ges. Psychologie*, 1932, **85**, pp. 230–236. In the numerator of formula 25 on p. 235 the sign must be changed.

We assume that the manifold of the intermediate steps is measurable. The numbers 1, 2, . . . 10, then, are symbols of quantity which we may use in the usual way. This enables us to determine the constants of the psychometric functions in a new way, since both entries of Table 4 refer to ordinary quantities. The table gives the empirical determinations of the probabilities of the judgments and the data have exactly the form needed for the application of the generalized method of constant stimuli. I do not attempt to outline the course of this calculation, for anybody interested in these technical matters may look it up in my paper in the *Archiv.*

The following table shows the results for the lower limit of the interval of uncertainty, for the point of subjective equality, and for the constant h. To each one of these quantities a double column is given, the one marked I referring to the values found under the supposition of the measurability of the manifold of the intermediate steps, and the one marked II giving the values found independently of this hypothesis.

TABLE 7

Standard	S_1		h		ξ	
	I	II	I	II	I	II
2	64.86	68.32	0.0345	0.0506	71.09	73.14
3	77.40	79.39	0.0337	0.0391	83.91	85.40
4	90.58	92.07	0.0329	0.0353	97.40	98.05
5	104.40	104.65	0.0321	0.0320	111.57	111.27
6	118.92	118.74	0.0313	0.0297	126.46	124.95
7	134.21	131.47	0.0305	0.0283	142.50	140.30
8	150.31	149.17	0.0297	0.0293	158.70	157.88
9	167.31	166.86	0.0289	0.0295	176.18	177.99
10	185.28	187.31	0.0281	0.0352		

The upper limit of the interval of uncertainty being equal for every standard to the lower limit of this interval for the next higher standard, it is sufficient to give the values of S_1 for standards 2, 3, . . . 10. The point of subjective equality for standard 10 can not be found directly and is omitted in the table.

There is just one pair of values—*h* for standard 1—for which the agreement between the two results is poor. In all the other cases the agreement is good, in many cases excellent even. There is no need for any further discussion and we formulate the conclusion in this way: *The supposition that the psychic manifold of the intermediate steps is measurable agrees well with the results of Thurstone's experiments.*

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THE RELATIVE QUICKNESS OF VISUAL AND AUDITORY PERCEPTION [1]

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I. INTRODUCTION

Historical Sketch.—Three methods of investigation have been used in studying the quickness or the relative quickness with which the perceptual processes may occur for the different sensory modalities: (1) simple reactions, (2) the so-called complication pendulum technique, and (3) a direct comparison of the stimuli. A large majority of these studies have been concerned with the quickness of the subject's response to visual and auditory stimuli. They have sought to throw light on the nature of the so-called 'personal equation,' which baffled the astronomers at the beginning of the nineteenth century.

It is obvious that the time of response (reaction time) to a stimulus is affected by the quickness with which the stimulus is perceived, but it does not necessarily indicate the speed of the perceptual process. Warren (1930), Woodworth (1929), and others hold that the mental process of perceiving takes place before the motor impulse starts. Quite recently Jacobsen (1930) has presented evidence to the effect that incipient motor impulses must accompany such mental processes as perceiving, imagining, and the like. It is the view of Myers (1928) that the psychological causes of the errors to which an astronomer is liable (the personal equation) may be accounted for simply by adding the alterations of apparent time order, produced by change of the field of attention, to the individual differences in reaction time. Just how this laborious process sheds light on the perceptual time is exceedingly difficult to understand. Indeed the reaction time experimentors have investigated only the quickness of the re-

[1] The writer is greatly indebted to Dr. Joseph Peterson for suggestions and criticisms in connection with the present study.

sponse—the time needed for a predetermined response to take place after the excitation of the receptor; they have not attempted to discover the interval of time at which a perception (or awareness) of the stimulus occurs. To hear a sound is quite a different experience from that of pressing a button.

The results obtained by means of the complication pendulum are too controversial to be given any consistent psychological interpretation. These experiments required the revolving of a pointer before a scaled clockface. At some moment of its revolution, unknown to the observer, a bell is sounded. The subject is to report the position of the hand at the moment the bell is heard. Here the problem is to discover the temporal relation of a single auditory impression to a continuous series of visual impressions, into the course of which the auditory is suddenly introduced. It was hoped that by this 'complication' technique reliable data might be secured in respect to the speed of the visual and auditory processes. Since Burrow's (1909) summary of these experiments Dunlap (1910) has shown the dependence of this type of procedure upon eye-movements, and Yoakum (1916) has reinvestigated and sought means of controlling the factor of after-images.

The results of these complication experiments have been vitiated not only by the errors due to after-images and eye-movements, but by such other uncontrolled factors as perception of time, space, position and movement. Furthermore, the experiments have not taken into account factors of adaptation, intensities of the stimuli, and the phenomena of sound localization.

A third and more direct method of approach to the problem was introduced by Exner (1875). His subjects were required to determine the time order of nearly simultaneous clicks and flashes. Results obtained by Exner were to the effect that in order for the light to be perceived first it must precede the sound by an interval of 160 milliseconds (thousandth of a second, abbr. ms) [2] before 75 percent of the

[2] The writer is following Boring's (1930, p. 362) suggestion in using the term *millisecond* rather than *sigma* as an expression of thousandth of a second. The term is abbreviated *ms.*

judgments were correct. On the other hand if the sound preceded the light by an interval of 63 ms it was perceived first. Several investigators have repeated Exner's experiment, but with discordant results. Gonnesiat (1892), Peters (1905), and Minnemann (1911) find results that agree in the main with those obtained by Exner. Bloch (1887), Tracy (1893), Hamlin (1893), Weyer (1903), and Whipple (1899), on the contrary, find that the order flash-click is more easily recognized. It was found that the order was not affected by 'serial' or 'single pair' presentation of the stimuli. It is suggested by the former group of experimentors that the difference in the perceptual time is due to a greater lag in the reception of the visual stimulus, but the latter group claim their results are due to the greater 'attention-claiming quality' attaching to the flash.

The Problem.—Myers (1928, p. 315) concludes from the experiments on the method of direct comparison of the stimuli that "For a flash of light to be perceived earlier than a momentary sound, the light must precede the sound by from 60 sigma to 100 sigma; when this interval falls to be about a quarter of this value the sound is experienced before the light." Apparently this conclusion is taken from Exner's data, which are not statistically reliable, and at the same time are vitiated by the uncontrolled factors referred to above. An examination of the literature fails to disclose any systematic investigation of the present problem. In the studies reported no attempt has been made to control the effects of varying the intensities of the stimuli, or to balance the so-called 'attention-claiming qualities' attaching to the stimulus. The lag in the flashing speed of the light and the reaction time of the sound stimulus has not been taken critically into account. These and other sources of error we have sought to control in our attack on the problem.

On a purely *a priori* basis it would seem that the above conclusion from Myers would be affected if we vary the intensities of either the visual or the auditory stimulus. This, in part, is the problem to which we have addressed ourselves. More specifically, we shall attempt to determine the relative

speed of the visual and auditory processes when varying intensities of the sound stimulus are paired with varying intensities of the light stimulus.

II. Experimental

Apparatus.—Plate 1 shows a perspective drawing of the principal parts of the apparatus used throughout this experiment. The upper half of the drawing shows the part that was used in the experimentor's room; the lower half was placed on a table in a darkened room across a hall way from where the experimentor worked. The apparatus was constructed so as to present simultaneously or nearly simultaneously (at predetermined intervals) a click from either of the four sounders with a flash from either of the four lights. This manner of presentation was accomplished by means of the switchboard attached to the dial of the Hopkins chronoscope. The rotating hand was used to make and break the electric currents which produced the stimuli. The short end of the hand was extended by means of a non-conducting attachment so that it would close the circuit on one of the contacts and not affect the other: the long end of the hand closed only the left contact. These contacts would be closed for an interval of only 20 ms. This was about the least interval that would permit the full flash of the brighter lights to occur. The current for the sounders was produced by means of three dry-cell batteries. The lights were connected with the 110 volt current from which the building is lighted.

Since the hand on the dial of the chronoscope rotates at a constant speed (69 times per minute with the Tungar rectifier), the interval between the light and sound can be definitely determined and conveniently varied by moving either of the contacts one way or the other from the position of simultaneous presentation (shown in the drawing). The clamps to which the contacts were fastened were constructed so that their positions could be changed within two or three seconds and with a very fine degree of accuracy.

The four different light intensities were produced by ordinary Mazda lamps of 15, 25, 40, and 75 watts, respectively. These lights were placed 80 centimeters from position of subject's eyes and just above the end of a white cardboard cylinder 25 cm in diameter: they were entirely concealed from the field of vision. Directly behind this cylinder was a white surface which aided in reflecting the light somewhat evenly over the entire surface exposed to subject's eyes. The intensity of these lights from the position of subject's eyes was 0.2, 4, 16, and 32 foot-candles, respectively, in the order named above. Hereinafter these lights will be designated with the letters *A*, *B*, *C*, and *D*; letter *A* being for the dimmest, as produced by the 15 watt bulb, etc.

The determination of the flashing speed of these lights presented a problem of considerable difficulty. It appeared from an examination of the literature in the physics journals that no such determinations had been made in the case of an ordinary line of simplified Mazda lamps.[3] A detailed description of our attack on this particular problem cannot be given in this paper. Owing to a lack of adequate laboratory facilities, we decided to attack the problem by making use of the principle (or law) of free-falling bodies.

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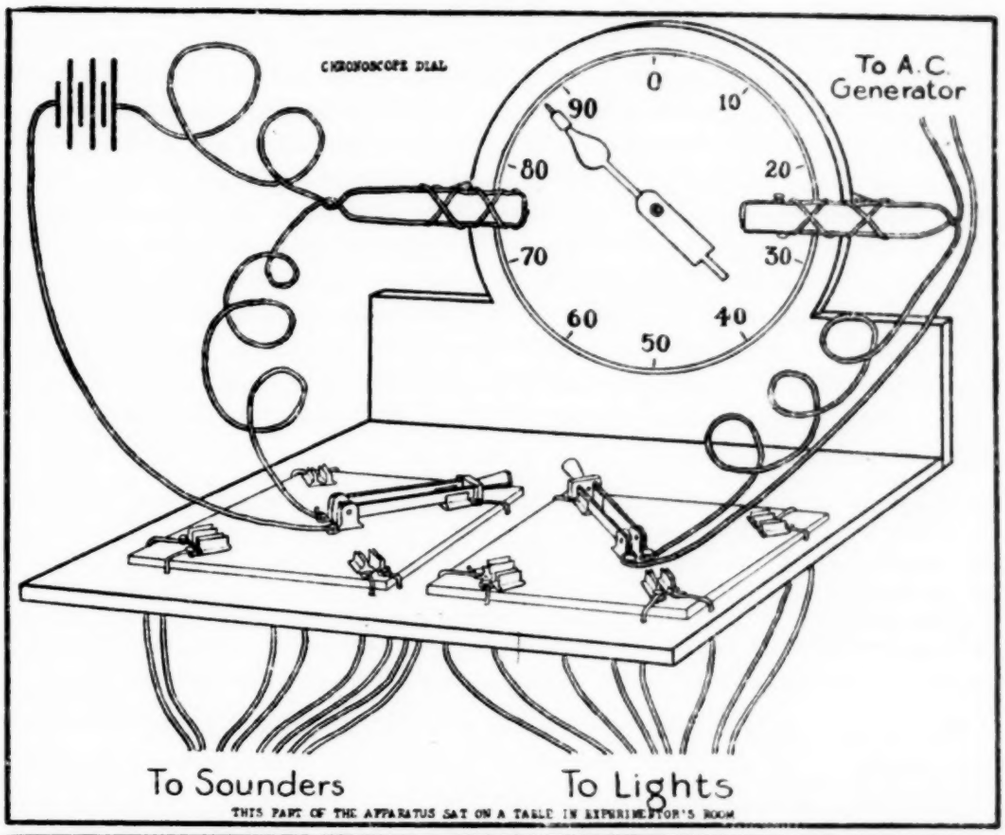
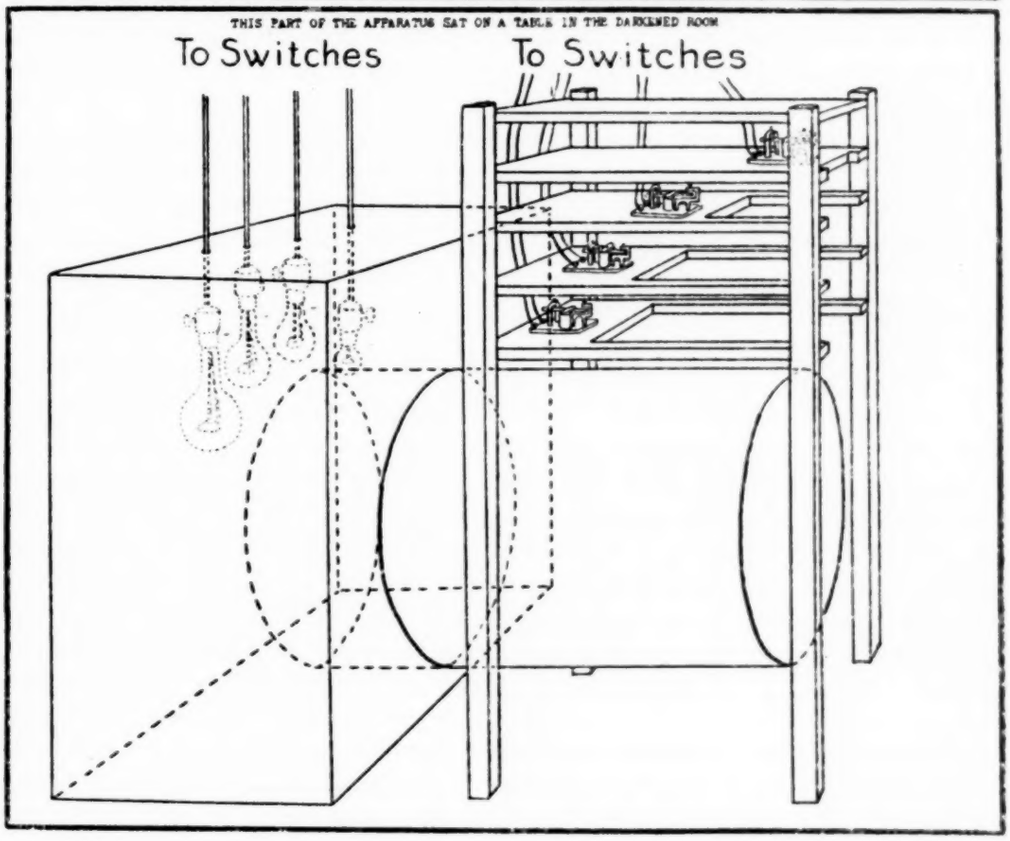
[3] Dr. Forsythe of the General Electric Company writes me that he is just beginning such an experiment. He expects to determine the flashing and cooling-off speed of a simplified line of the ordinary Mazda lamps on a 110 volt circuit.

PLATE I.


CHRONOSCOPE DIAL
To A.C. Generator
0
10
20
30
40
50
60
70
80
90
To Sounders
To Lights
THIS PART OF THE APPARATUS SAT ON A TABLE IN EXPERIMENTOR'S ROOM


THIS PART OF THE APPARATUS SAT ON A TABLE IN THE DARKENED ROOM
To Switches
To Switches

The falling object was a wooden frame 10″ × 22″ with a movable cardboard attached. When this frame had fallen a given distance (254 mm in these measurements) it closed a contact which turned on the light. This light bulb was enclosed in a small box containing an opening 5 mm in width. The cardboard attached to the falling frame could be moved upward from the position of the contact until the onset of the flash was just visible. At this point the part of the flash at which the wire was barely red could be observed and the time-interval easily calculated. By increasing the distance of the cardboard from the point of contact we could obtain the time-period for the occurrence of the maximum brightness. The resistance offered by the air and the closing of the contact was so slight as to be practically negligible for our measurements. By this method we were able to determine within approximately 0.1 ms the time-period of the onset and maximum brightness of the flash of the different light bulbs. Obviously, the period of maximum brightness was much more difficult to determine than the period of the onset. The following flashing speeds were obtained for the four light bulbs used:

	15-watt	25-watt	40-watt	75-watt
Time in ms for:				
Onset of flash	6.2±0.4	8.8±0.5	10.1±0.8	11.0±1.7
Complete flash	11.8±2.3	14.7±2.8	17.0±3.6	24.0±6.0

By the same procedure we were able to determine the reaction time of the telegraph sounders. By arranging the sounder so that the fall of the hammer against the diaphragm would admit a beam of light through a small opening we could determine the time required for the occurrence of the click. The adjustment of the movable cardboard to the point at which the light became visible gave the distance traversed by the falling frame from the time the contact was closed until the hammer hit the diaphragm. This distance was approximately 19 mm; and since the frame had fallen 254 mm when the contact was made, the additional space described required an interval of 8.4 ms.[4] This interval we have assumed to be the reaction time of the telegraph sounders. These results are in close agreement with those obtained in physics laboratories. Minnemann (1911, p. 341), working by photographic methods, found the time period for the lag in similar instruments to be 8.7 ms. No results are available at present with which we can compare the measurements obtained on the flashing speed of the Mazda lamps.

The four sounders were placed radially in the median plane at a distance of 10 cm apart and 33 cm from subject's ears. This arrangement was meant to prevent possible effects of localization phenomena, and other 'attention claiming qualities' of the stimulus. An attempt was made to express quantitatively the intensity differences of the clicks produced by the sounders. Since the intensity of a sound (for the physicist) produced by a falling body is directly proportional to the height of the fall, we can easily calculate the approximate intensities of the different clicks. This was done by making a number of comparisons of the height from which a metallic weight was required to fall in order to produce a sound apparently equal in intensity to the one employed. Following this procedure and expressing the intensities in terms of gram-

[4] Kymographic measurements showed that the time required for the hammer to fall from position of rest to the diaphragm was only .3 ms in case of the loudest sounder. Such measurements were not made on the other three sounders.

centimeters (g cm) of kinetic energy released, we have 0.2, 3, 20, and 72 g cm, respectively, for the four sounds. Hereinafter these sounds will be designated with the numbers 1, 2, 3, and 4, in the order of intensity, 1 being the faintest click and 4 the loudest. These sounders were arranged on the shelves in the order of increasing intensity from the top to the bottom, the loudest being on the bottom shelf.

Procedure.—The subjects consisted of 80 college students (14 men and 66 women) taking work in general psychology in the Jesup Psychological Laboratory. They were all unpracticed in this particular discriminatory process. Each subject observed alone in a darkened room relatively free from any distracting noise of the chronoscope or other outside influences. The total time required of each subject was approximately one hour. This time was divided into two sittings of 30 minutes each, which for the most part came on successive days. The subjects were arranged by a chance order into two groups, *A* and *B*, with 40 members in each group. Members of both groups were instructed orally (and individually) as follows:

> In this experiment you will be given a number of trials in which a flash of light and a click of a telegraph sounder will be presented apparently together or with only a very short interval between them. The presentation of these stimuli will follow a chance order. A trial will consist of a series of 10 presentations occurring at about 1 second apart, or a total time of 10 seconds. Furthermore, the different trials will consist of different combinations of stimulus intensities, but no intensity change will occur during the presentations of the particular trial. In many of the trials your judgments will be very difficult to determine, so when you are in doubt you must guess.

Members of Group *A* were further instructed as follows:

> Your task is to determine which stimulus appears to be presented first. No doubtful reports must be given. You will communicate your report to me at the end of each trial by pressing this key (which connects with a telegraph sounder in my room) once if the light is perceived first, and twice if the sound is perceived first. An interval of about 5 seconds will elapse between each trial.

Members of Group *B* received the further separate instructions:

> You are to determine whether or not there is an interval between the paired stimuli—are they perceived simultaneously or is there a slight interval between them. No doubtful reports must be given. At the end of each trial you will communicate your report to me by pressing this key (which connects with a telegraph sounder in my room) once if the stimuli fuse (perceived simultaneously) and twice if an interval was noticed. An interval of about 5 seconds will elapse between each trial.

Each subject was given a few preliminary presentations with clearly noticeable intervals between the stimuli and also when the stimuli were nearly simultaneous; also some of the intensity combinations were given. This preliminary training was fairly constant for all the subjects.

Since either of the four lights could be paired with either of the four sounds, we had sixteen combinations of stimulus intensities. A chance order of presentation was followed, not only for the intensity combinations but for the ms-interval between the paired stimuli in each successive trial. In all, each subject was given 144 trials, one-half of which followed the click-flash order and one-half the flash-click order. From each subject, therefore, we obtained a total of 1,440 judgments. This would give for the 80 subjects a grand total of 115,200 judgments to be used in the following treatment of our results.

Results.—It was planned to present the stimuli simultaneously and at intervals of 15, 30, 60, and 100 ms between

the stimuli for both click-flash and flash-click orders of presentation. These intervals could not very well be used due to the lags in the lights and sounders, and to the fact that the hand on the dial rotated 69 times per minute instead of 60 times. The intervals, therefore, between the onset of the two currents (producing the clicks and flashes) were 0, 13, 26, 52, and 87 ms. The clamps on the dial could be adjusted to these intervals quickly and accurately. Now if the two contacts were closed simultaneously (see position as shown in Plate I), the click from either of the four sounders reached subject's ears 2.4, 5.3, 7.6, and 12 ms earlier than flashes from the lights *A*, *B*, *C*, and *D*, respectively. For the click-flash order these lag differences must be added to the interval between the onset of the two currents: for the flash-click order the differences must be subtracted from this interval. This situation accounts for the differences in the intervals between the paired stimuli for the different light intensity combinations as will be noticed in Tables I and II.

In Table I we have given the results obtained from Group *A*. The intensity combinations are shown in the first column at the left. The figures under the letter *S* designate the sound intensity (see p. 9) and the letters under *L* designate light intensities (see p. 6). The interval between the stimuli is indicated by the numbers just above the line for each of the four sets of figures. Thus the 89.4 in the upper left corner of the table means that the sound preceded the light this number (89.4) of milliseconds (.001 sec) when light-*A* was presented. Similarly the 84.6 at the right end of this line means that the light preceded the sound this many ms for the intensity combinations shown at the left. In like manner may the intervals be read for the remaining intensity combinations. (These designations apply similarly for Table II.) The two columns at the right show the time necessary to give 75 percent correct judgments for both the click-flash (*C–F*) and the flash-click (*F–C*) orders of presentation.

The threshold values for each group of subjects were determined in accordance with the criterion (basis of judgment) used. Since for Group *A* 50 percent of the judgments

TABLE I

PERCENTAGE OF LIGHTS AND SOUNDS PERCEIVED FIRST BY GROUP *A* FOR THE DIFFERENT INTENSITY COMBINATIONS AT VARIOUS MS INTERVALS BETWEEN THE PAIRED STIMULI.

Intensity	Sound Presented First in ms. Intervals					Light Presented First in ms. Intervals				Time in ms. Necessary to Give 75% Threshold	
S-L	89.4	54.4	28.4	15.4	2.4	10.6	23.6	49.6	84.6	*C-F**	*F-C**
1-A	90.0	82.5	67.5	60.0	50.0	62.5	72.5	82.5	87.5	41.0	30.1
2-A	90.0	80.0	75.0	55.0	50.0	67.5	75.0	85.0	90.0	28.4	23.6
3-A	97.5	92.5	75.0	65.0	57.5	57.5	67.5	77.5	90.0	28.4	43.0
4-A	97.5	85.5	82.5	70.0	62.5	50.0	55.0	82.5	85.0	20.4	42.5
	92.3	57.3	31.3	18.3	5.3	7.7	21.7	46.7	81.7		
1-B	92.5	75.0	67.5	50.0	60.0	70.0	80.0	87.5	90.0	57.3	14.7
2-B	97.5	87.5	75.0	57.5	47.5	62.5	67.5	80.0	97.5	31.3	36.7
3-B	97.5	87.5	77.5	72.5	55.0	57.5	70.0	80.0	95.0	24.8	34.2
4-B	95.0	92.5	72.5	62.5	52.5	60.0	70.0	80.0	92.5	27.4	34.2
	94.6	59.6	33.6	20.6	7.6	5.4	18.4	44.4	79.4		
1-C	80.0	82.5	70.0	55.0	40.0	67.5	80.0	95.0	92.5	44.0	13.2
2-C	92.5	80.0	67.5	55.0	45.0	65.0	70.0	80.0	92.5	49.2	31.4
3-C	95.0	85.0	72.5	65.0	52.5	70.0	72.5	82.5	92.5	38.8	35.0
4-C	97.5	95.0	67.5	52.5	45.0	60.0	65.0	87.5	90.0	40.6	30.0
	99	64	38	25	12	1	14	40	75		
1-D	80.0	72.5	65.0	50.0	35.0	70.0	80.0	85.0	87.5	75.5	7.5
2-D	87.5	75.0	65.0	45.0	37.5	72.5	75.0	85.0	87.5	64.0	14.0
3-D	87.5	77.5	72.5	57.5	45.0	57.5	75.0	82.5	90.0	51.0	14.0
4-D	90.0	77.5	70.0	60 0	57.5	52.5	72.5	87.5	97.5	55.3	18.3

* *C-F* means click-flash order, *F-C*, flash-click order.

(at simultaneous presentation) should be correct by chance, the place at which the stimulus difference is as often appreciable as inappreciable should occur near the 75 percent threshold. Applying this principle of deducing thresholds (*Cf.* Myers, 1928, p. 197) to the judgments of Group *B*, it is clear that this value should be placed at that distance in ms from simultaneous presentation at which an equal number (50 percent) of intervals and fusions are perceived. The intensity effects upon the size of the thresholds for Group *A* are represented graphically in Figs. 1 and 2.

The curves in Fig. 1 show the effects of increasing the intensity of the light upon the quickness with which either of the

paired stimuli may be perceived first for the click-flash and the flash-click orders of presentation. Thus if *S*-4 is presented with *L–A* (.2 f c) it (*S*-4) is perceived first when the interval between the two stimuli is only 20.4 ms; but if the light is presented first it will be perceived first when the interval is 42.5 ms. If it is made brighter the intensity effects are clearly noticeable. The size of the threshold increases to 55.3 ms when the bright light (32 f c) is paired with the same

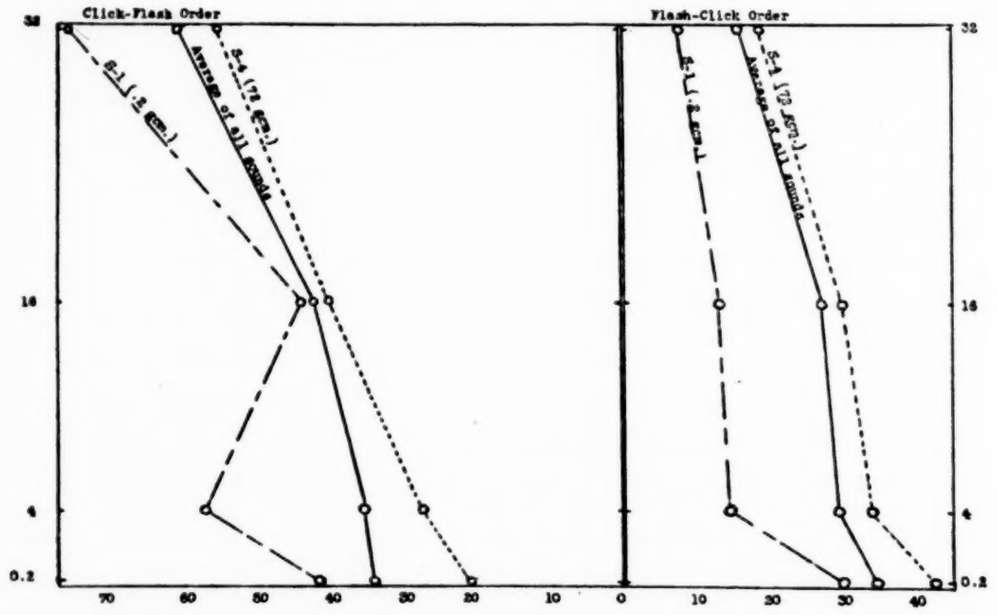


FIG. 1. Illustrating the thresholds for the different intensity combinations along the light continuum (Group *A*). Ordinates represent light intensity in foot-candles; abscissæ represent millisecond-iutervals from simultaneous presentation.

sound for the click-flash order, and decreases to 18.3 ms for the flash-click order. The intensity effect in the former case is to retard the speed of the auditory process 35.1 ms, and at the same time the visual process is accelerated 24.2 ms. The curves show somewhat similar effects when the faint sound (*S*-1) is paired with the same lights. The smooth line is a composite (average of the thresholds of the four sound intensities) curve and shows that intensity effects are fairly constant at all points along the light continuum for both orders of presentation. The flash-click order is recognized earlier when the brighter lights are used but not necessarily in case of the dimmer lights. The distances of the curves from each other

indicate intensity effects of the auditory stimuli, but these effects are represented more clearly in Fig. 2.

Figure 2 shows the thresholds for the intensity effects along the sound continuum. As in Fig. 1 the curves represent strong and weak stimulus intensities. It is noticed that a sound intensity beyond that of 20 g cm (S-3) has little or no effect upon the time for the click-flash or the flash-click order

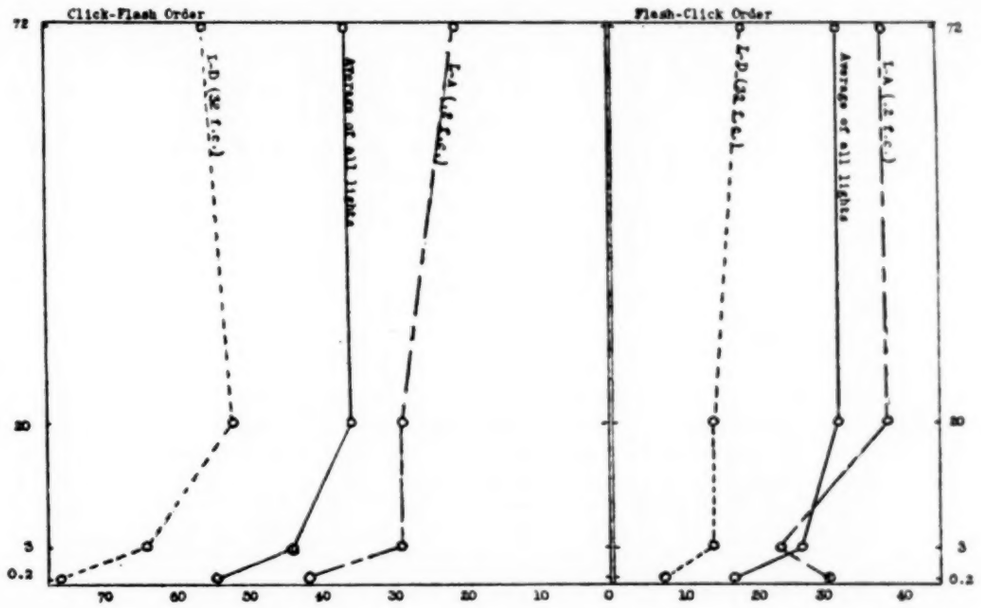


FIG. 2. Illustrating the thresholds for the different intensity combinations along the sound continuum (Group *A*). Ordinates represent sound intensity in gram centimeters; abscissæ represent millisecond-intervals from simultaneous presentation.

of recognition. The composite curve (smooth line) shows the general trend of intensity for both orders of presentation along the sound continuum.

The curves in Figs. 1 and 2 show a decided tendency to perceive the light earlier than the sound. Exceptions to this tendency, however, are found when the louder sounds are presented with the dim lights. We cannot say that a sound is as loud as a light is bright: it may be possible so to equate visual and auditory stimuli but we have made no attempt to do so. The thresholds give some indication as to how bright a light must be in order to be perceived as quickly as a sound of a given intensity, and *vice versa*. Some further light on the problem may be seen by examining the results obtained from Group *B*.

TABLE II

PERCENTAGE OF INTERVALS PERCEIVED BY GROUP *B* FOR THE DIFFERENT INTENSITY COMBINATIONS AT VARIOUS MS INTERVALS BETWEEN THE PAIRED STIMULI

Intensity	Sound Presented First in ms. Intervals					Light Presented First in ms. Intervals				Time in ms. Necessary to Give 50% Threshold	
S-L	89.4	54.4	28.4	15.4	2.4	10.6	23.6	49.6	84.6	*C-F**	*F-C**
1-A	82.5	67.5	50.0	30.0	22.5	27.5	37.5	67.5	87.5	28.4	34.4
2-A	95.0	60.0	52.5	20.0	17.5	22.5	37.5	67.5	80.0	27.3	34.4
3-A	82.5	70.0	52.5	25.0	17.5	20.0	30.0	52.5	75.0	27.2	46.7
4-A	92.5	77.5	57.5	27.5	22.5	25.0	32.5	50.0	82.5	25.9	49.6
	92.3	57.3	31.3	18.3	5.3	7.7	21.7	46.7	81.7		
1-B	90.0	75.0	47.5	35.0	17.5	20.0	35.0	67.5	80.0	33.6	32.7
2-B	85.0	77.5	60.0	22.5	20.0	27.5	32.5	65.0	90.0	28.3	34.7
3-B	90.0	80 0	40.0	22.5	17.5	30.0	40.0	77.5	87.5	37.8	30.2
4-B	90.0	70.0	30.0	25.0	20.0	25.0	35.0	60.0	82.5	41.7	41.2
	94.6	59.6	33.6	20.6	7.6	5.4	18.4	44.4	79.4		
1-C	87.5	67.5	60.0	25.0	22.5	27.5	32.5	65.0	82.5	29.9	29.3
2-C	90.0	75.0	42.5	30.0	20.0	25.0	32.5	60.0	92.5	39.3	34.9
3-C	82.5	77.5	47.5	22.5	25.0	17.5	27.5	70.0	92.5	37.7	32.1
4-C	72.5	65.0	32.5	17.5	22.5	25.0	35.0	65.0	87.5	47.3	31.4
	99	64	38	25	12	1	14	40	75		
1-D	67.5	60.0	47.5	25.0	27.5	30.0	35.0	62.5	87.5	43.2	28.4
2-D	72.5	62.5	50.0	25.0	30.0	35.0	45.0	67.5	92.5	38.0	19.7
3-D	75.0	70.0	45.0	27.5	20.0	32.5	55.0	80.0	90.0	43.2	21.1
4-D	80.0	67.5	50.0	25.0	20.0	27.5	52.5	77.5	80.0	45.6	14.2

* *C-F* means click-flash order, *F-C*, flash-click order.

Group *B* was to determine whether or not an interval was perceptible between the paired stimuli (see p. 250). Table II shows the percentage of intervals perceived between the stimuli for the various intensity combinations for the click-flash and flash-click orders of presentation. The intensity combinations and the intervals (not the recognized intervals) occurring between the paired stimuli are the same as those given in Table I. The thresholds are for the time in milliseconds necessary to give 50 percent of correct judgments. The situation here is comparable to that of obtaining the two-point limen for cutaneous sensitivity. The thresholds for each intensity combination (for both groups of subjects) were obtained from approximately 3600 judgments (400 for each

interval between the paired stimuli). The results obtained from Group *B* are represented graphically in Figs. 3 and 4.

Figure 3 represents intensity effects along the light continuum upon the quickness with which an interval may be perceived between the paired stimuli. These results correspond to those represented in Fig. 1; they were obtained under approximately the same conditions—the same order of stimulus presentations and intensity combinations. The main

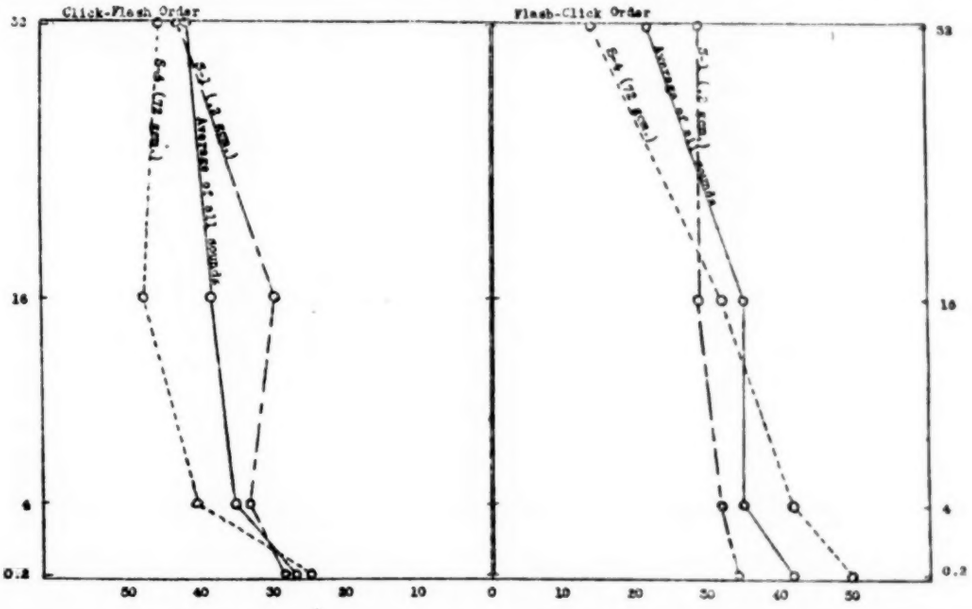


FIG. 3. Illustrating the thresholds for the different intensity combinations along the light continuum (Group *B*). Ordinates represent light intensity in foot-candles; abscissæ represent millisecond-intervals from simultaneous presentation.

difference was in respect to the basis of judgment employed by the two groups. These curves (Fig. 3) show similar intensity effects though not as pronounced as those observed in Fig. 1. An increase in the light intensity is more noticeable in case of the click-flash order in Fig. 1, but in Fig. 3 the greater effect holds for the flash-click order. Thresholds represented in Fig. 4 show the effects of increasing the sound intensity on the quickness with which intervals may be observed between the stimuli.

Figure 4 shows a rather peculiar situation in regard to the intensities of the auditory stimulus. If the intensity of the sound is increased there is little or no effect on the quickness with which intervals are perceived. This relationship holds

especially for the lights *L–A* and *L–D* when the click-flash order is followed; for the flash-click order there is a kind of a reverse intensity effect noticed when the bright and dim lights are paired with the louder sounds. The average values for the thresholds for the four lights form a line (composite curve) almost parallel to the *O*-line (the double line in the center),

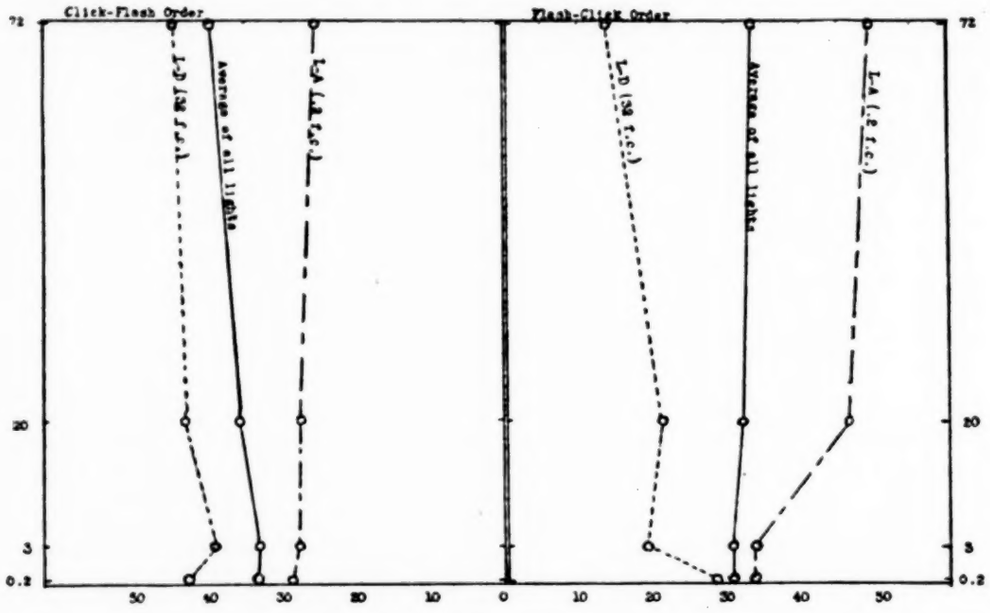


FIG. 4. Illustrating the thresholds for the different intensity combinations along the sound continuum (Group *B*). Ordinates represent sound intensity in gram centimeters; abscissæ represent millisecond-intervals from simultaneous presentation.

thereby showing no intensity effects along the sound continuum. The fluctuations, however, for the flash-click order are great enough to be significant. Just what the factors were that produced these effects, we cannot say. Figure 2 (p. 13) shows results obtained from Group *A* corresponding to those represented for Group *B* in Fig. 4. The main difference in the two figures is seen in the intensity effects for the fainter sounds. These differences and many of the other irregularities in the curves are probably due to (1) inhibitory effects resulting from tensions, sets and attitudes, (2) to relative difficulties inhering in the basis of judgment, or (3) to some uncontrolled defect in the apparatus.

It is well known that measurements of discriminatory functions can be made only when there is confusion or diffi-

culty involved with respect to the stimulus differences to be discriminated. The larger the number of judgments obtained in any psychological measurement the less pronounced are the effects of individual differences and the greater the reliability of the measurements obtained. In Fig. 5 we have combined the averages of the thresholds for both groups of subjects for the different intensity combinations.

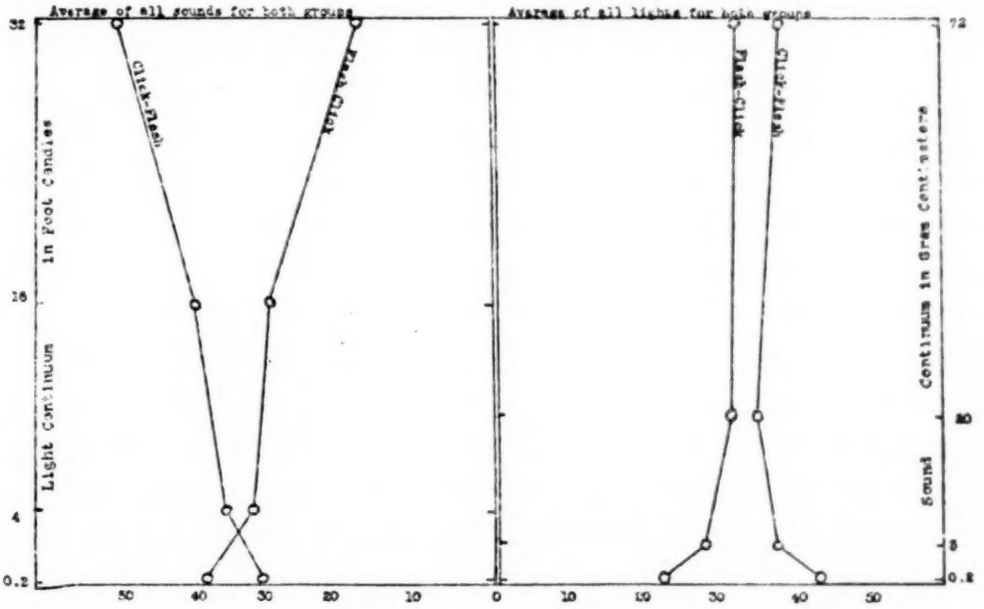


FIG. 5. Illustrating the combined averages of the thresholds for both groups for different intensity combinations. The left half shows the average intensity effects along the light continuum; the right half shows the intensity effects along the sound continuum. Ordinates represent the stimuli continua; abscissæ represent millisecond intervals from simultaneous presentation.

The recognition of an interval, of course, has some relation to the quickness of perception. Similarly the extent of the interval of fusion between two stimuli has been used as an index to the quickness of perception. Gonnesiat's (1886) problem was to measure the interval by which a visual stimulus (the instantaneous flashing of an artificial star) may precede an auditory stimulus (telephone click) and yet have both appear simultaneous. He found that the light may be presented 50 ms earlier than the sound before synchronization ceased. Each of the thresholds in Fig. 5 was determined from approximately 12,800 judgments (6,400 for each group—see Tables I and II)—a number great enough to smooth out

many of the accidental differences. These curves are based on the assumption that the bases of judgments were equally valid for the two groups. Granted this assumption, the curves present a rather interesting situation. The curves at the left show the effects of increasing the light intensity on the order of presentation. Light-*A* (.2 f c) was presented first with all the sounds 6,400 times and their threshold interval averages 38.0 ms. For the click-flash order they are perceived 9.6 ms earlier. If the same sounds are presented with the brightest light (32 f c) the average threshold interval is 17.1 ms, or a general intensity effect of 20.9 ms for the flash-click order. For the click-flash order this intensity effect is 23.4 ms. This indicates that the order of presentation has (scarcely) no effect on the interval of uncertainty when the light intensities are increased. The right side of the figure (Fig. 5) shows the effects of increasing the sound intensity on the thresholds of all lights for both groups for the click-flash and flash-click orders of presentation. If the sound is made louder the interval of uncertainty is decreased for the click-flash order and increased for the flash-click order. But these effects do not hold for the two louder sounds. Here (along the sound continuum), we find that the order of presentation has little or no effect on the interval of uncertainty.

Conclusions.—The evidence we have presented shows that the relative quickness of visual and auditory perception is affected by changes in the intensity of either stimulus. The individual differences were so great that the results obtained by any of the previous investigators could be matched with samplings from our individual records. Some of the subjects in Group *A* perceived the click first when the interval between the flash-click order was nearly 100 ms, and some perceived the flash first when the interval between the click-flash order was just as large. This situation was found for all the intensity combinations used.[5] Individual differences were probably

[5] The actual number of subjects reporting clicks or flashes perceived first or simultaneous impressions may be determined by reference to Tables I and II. The percentage columns may likewise refer to the percent of 40 subjects so reporting. For example, the 90 just opposite 1-*A* in the second column of Table I also shows that

greater for the subjects in Group *B*. Intensity changes also affect the quickness with which an interval may be recognized between the two stimuli. Changes in the intensity of the lights used in this experiment had a more pronounced effect on the order of recognition (basis of judgment for Group *A*) than on the perception of an interval between the stimuli (basis of judgment for Group *B*). Furthermore, intensity changes of the lights were more effective than the intensity changes of the sounds; but we cannot say that these stimulus intensities were comparable. Equal intensity effects may result from comparable stimuli, but we find evidence that precludes such an assumption. This evidence is found in Figs. 2 and 4. Here we find increases in the auditory stimulus where no effects were produced on the judgments of either group of subjects.

In the main, our findings lend support to the results obtained by Hamlin (1893), Whipple (1899) and others who found that the flash-click order was more easily recognized. But for some of the intensity combinations the click-flash order was recognized more quickly. The stimulus intensities may be so equated that both orders of presentation will be recognized when the interval is the same.

Thresholds were obtained for the sixteen intensity combinations for both click-flash and flash-click orders (see Tables I and II) and were represented graphically in Figs. 1–5. When these thresholds are averaged for both groups of subjects and represented on a stimulus continuum, we find that the order of presentation has no appreciable influence on the intensity effects of the stimulus.

The results of our experiment are in accord with those obtained on closely related problems. Hamlin (1893), Exner (1875), and Banister (1926) have measured the least noticeable interval between two sounds. The interval required to give 75 percent of right judgments was as small as 5 ms for some subjects and as large as 64 ms for others. Intensity

for this intensity combination 4 subjects perceived the light first when the click preceded the flash 89.4 ms. At the right end of this same line the 87.5 shows that 5 subjects perceived the click first when the light preceded the click 84.6 ms. In like manner may all the other percentages be read.

effects were not investigated. Dunlap (1915) has measured the least perceptible interval between two lights. This (perceptible) interval was found to depend upon the relative duration of the stimuli and the dark interval. When the two stimuli were equal in length to the dark interval the least perceptible interval was approximately 20 ms. However, Minnemann (1911) found that the duration of the light had no effect on the least noticeable interval between clicks and flashes. The least noticeable interval between the most rapid successive movements of two hands has been investigated by Klinger (1931). If the hands moved in the same direction the interval was 26.5 ms; if they moved in opposite directions the interval was 29 ms. These differences, however, were probably due to the two types of apparatus employed to produce the movements. The writer is at present attempting to measure the effects of the wave lengths of different spectral hues upon the quickness of visual perception. Preliminary results seem to indicate that yellows and greens are perceived more quickly than the hues having longer and shorter wave lengths. These groups of experiments indicate that the noticeable interval between stimuli presented to the same sense is within the approximate range of that observed when the stimuli are presented to disparate senses.

The practical applications to be drawn from this study are those which relate to the personal equation and the temporal attributes in various psychophysical situations. Not infrequently are we required to contrast the simultaneous with the successive; to take into account the various objective processes with which the organism is continually confronted. Synchronization of the disparate impressions from the sound-film is an example at hand.

The possible relation or application of our results to the 'physiology of consciousness' cannot be elaborated just here. Visual and auditory theories cannot disregard the quickness with which their perceptual processes occur. Neuro-physiology must take into account the perceptual correlate of the summation process, whether this process be a functional

summation of impulses in a behavioral response or an actual collection of ion charges from single or separate nerve fibers.

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References

Banister, H, A suggestion towards a new hypothesis regarding the localization of sound, *Brit. J. Psychol.*, 1926, **17**, 142–153.

Boring, E. G., A note on the use of sigma, *Science*, 1930, **71**, 362.

Burrows, N. T., The determination of a momentary impression, *Psychol. Rev. Monog.*, 1909, **47**, 1–63.

Bloch, A. M., Exnerschen ähnliche Versuche mit analogen Ergebnissen, *Rev. Scientifique*, 1887, S. 585.

Dunlap, K., The complication experiment and related phenomena, *Psychol. Rev.*, 1910, **17**, 151–191.

Dunlap, K., Least noticeable interval between two lights, *Psychol. Rev.*, 1915, **23**, 226.

Exner, S., Untersuchungen uber die einfachsten psychischen Prozesse. IV. Abhandlung, *Pflugers Archiv.*, 1875, **11**, (Results taken from Peters, 1905, p. 401).

Gonnessiat, Recherches sur l'équation personnelle. Paris, 1892, pp. 138–140, (Results taken from Hamlin, 1893, p. 565).

Hamlin, A. J., Least observable interval between stimuli addressed to the same sense and to disparate senses, *Amer. J. Psychol.*, 1893, **6**, 564–573.

Jacobsen, E., Electrical measurements of neuromuscular states during mental activities, *Amer. J. Physiol.*, 1930, **91**, 567–608; **94**, 22–34.

Klinger, G., Die Herstellung der Mindestzeit zwischen zwei Handlungen bei vorgeschriebener Reihenfolge, *Arch. f. d. ges. Psychol.*, 1931, **82**, 105–152.

Minnemann, C., Untersuchungen uber die relativ Geschwindigkeitauffassung fur Gesicht- und Schallreizen, *Arch. f. d. ges. Psychol.*, 1911, **21**, 230–357.

Myers, C. S., A text-book of experimental psychology, 1928.

Peters, W., Aufmerksamkeit u. Zeitverschiebung in d. Auffassung disparater Sinnesreize, *Ztsch. f. Psychol. u. Physiol. d. Sinnesorgans*, 1905, **39**, 401–428.

Tracy, Results published by Hamlin (1893).

Warren, H. C., and Carmichael, L., Elements of human psychology. 1930.

Weyer, E. M., Die Zeitschwellen gleichartiger u. disparater Sinneseindrüke, *Philos. Studien*, Bd. **14** and **15**.

Whipple, G. M., On nearly simultaneous clicks and flashes, *Amer. J. Psychol.*, 1899, **10**, 280–286.

Woodworth, R. S., Psychology. 1929 (Revised edition).

Yoakum, C. S., The complication experiment and the after-image, *J. Exper. Psychol.*, 1916, **1**, 99–121.

AN ACTION CURRENT STUDY OF HANDEDNESS IN RELATION TO STUTTERING

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Introduction

Source of Action Currents

There would seem to be at least two sources of action currents, the receptor organs and nervous centers or nerve cells in the central nervous system. The receptor organs selectively translate the energy of one type or another from the environment into the energy of 'impulses' each of which is indicated by its electrical disturbance. The most conclusive evidence of this has been furnished by Adrian and his collaborators (1), (2), (3), (4), (5), (6). Certain groups of cells in the central nervous system may be rhythmically active, perhaps spontaneously and automatically. Adrian and Buytendijk (7) recorded large, slow rhythmic action current waves (occurring at intervals of 1 to 3 seconds) from the isolated brain stem of the gold fish and Bishop and Bartley (9), (10) recorded action potentials (3 per second) from an isolated region of the rabbit's cerebral cortex. Also Adrian (8) recorded spontaneous potential changes in the isolated nervous system of *Dystiscus Marginalis*. Regardless of their source once these action currents or impulses are set up they may travel to any and all parts of the central nervous system and to the various effectors. In doing this they are affected undoubtedly in various ways by the complex sets of forces in relationship with which they must come. Such sets of forces may be processes of inhibition, excitation and release, 'stored' energy, absolute and relative refractory phases, relations of conduction velocity, and length of circuits.

Nature of Action Currents

From the standpoint of recording techniques action currents are small alternating electrical currents. As recorded

from a muscle mass or a nerve trunk they consist of irregular, non-repeating electrical waves which become more regular in both amplitude and frequency as the number of responding units is reduced. They may be considered electrical manifestations of underlying activity of muscle and nerve or negative variations occasioned by a chemico-physical process in the active tissue. They present for study frequency, intensity and wave form. Of these characteristics frequency has received the most attention. Briefly, it is dependent upon the number of units active at a given time, the refractory periods of the active units which may be modified by the intensity of the stimulus, and the temporal relationships between the discharges of the various active units. In a muscle mass or nerve trunk the amplitude of the action currents is, within limits, directly proportional to the number of fibres responding in all-or-none fashion. The form of the action current waves is dependent upon the frequency, the intensity and the phase relationships of the various components contributed by the various active units.

Methods of Recording Action Currents

Action currents have been recorded by the galvanometer, the capillary electrometer, and the oscillograph. The common present method is to use the oscillograph in conjunction with appropriate amplifying units. The action currents are picked up from the responding tissue by means of relatively nonpolarizable electrodes such as needles, wires, plates, etc.

Apparatus and Procedure.—In the present study we utilized a three stage resistance-coupled amplifier with good intensity-frequency response characteristics, a Westinghouse oscillograph and a special photographic unit for recording the action currents. A general Radio Type 377-B low frequency oscillator furnished time units in terms of .002 sec. Recording was done on Eastman motion picture film and Eastman No. 1 sensitized paper, both being of standard size (35 mm). Our electrodes were two brass strips, two inches in length and one quarter inch in width, covered with canton flannel which was saturated with saline solution. They were curved slightly to conform to the curvature of the arm and fastened approximately one centimerer apart over the motor point of the fore-arm muscles (flexor digitorum sublimis).[1]

[1] For a more detailed discussion of our apparatus see Travis, L. E. and Lindsley, D. B., The relation of frequency and extent of action currents to intensity of muscular contraction. *J. Exp. Psychol.*, 1931, 14, 359–381.

The Smedley hand dynamometer was used to determine various intensities of contraction of the forearm muscle during voluntary flexion of the digits.

For the first record the subject was required to attain as rapidly as possible his maximum grip. Then with proper rest periods (one to two minutes) interspersed between contractions he continued in a descending order with the degrees of contraction decreasing by 10 kilograms each trial. For example, if the individual gripped 60 kilograms in the first maximum pull, he gripped 50 kilograms in the second trial, 40 kilograms in the third trial and so on down to 10 kilograms on the last trial. If the individual's maximum contraction was less than 50 kilograms, steps of 5 rather than of 10 kilograms were used. This furnished more readings on the basis of which to determine the action current frequency for the various intensities of contraction. Any given amount of contraction was not maintained longer than two seconds. Regardless of the handedness of the subjects records were taken from the right forearm first. As determined by our previous study (**12**) our present procedure eliminated fatigue as a factor in influencing our results.

In determining the frequency of the action currents every visible wave was counted regardless of its size (Fig. 1).

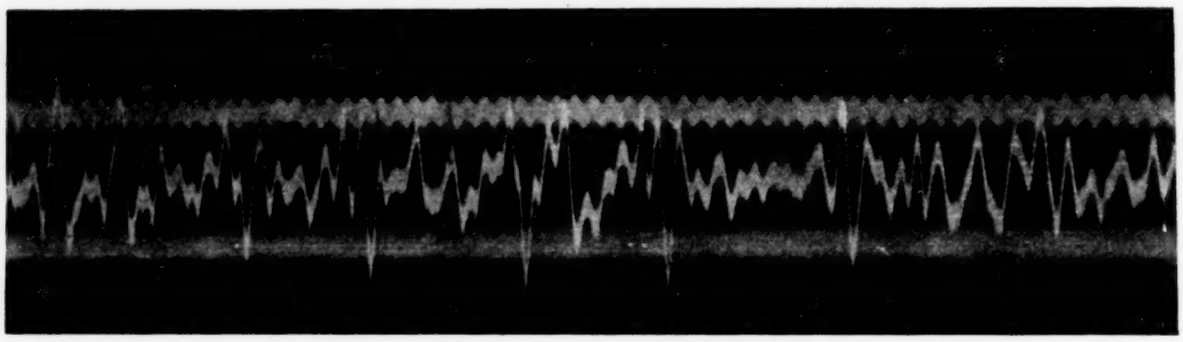

FIG. 1. A typical record of action currents. In reading frequency every visible wave was counted regardless of its size. Time in .002 sec.

Selection of Subjects.—To the entire freshman class of the University of Iowa was given the following laterality index test and an eyedness test. Over six hundred and fifty of the freshman students coöperated in this experiment. Eyedness was determined by a modified Parson technique. Instead of using Parson's manoptoscope (**11**) we used a card-board 8½ by 11 inches with a hole 13/16 inch in diameter in the center. The subject was required to hold the cardboard at arm's length squarely in front of his face and with both eyes open look through the hole at the bridge of the experimenter's nose. As with Parson's manoptoscope this procedure took advantage of the principle of unilateral sighting in binocular vision. The experimenter could tell easily which eye was being used by the subject. The subject held the cardboard in both hands for four trials, in the left hand for three trials and in the right hand for three trials. He was considered right- or left-eyed if he used either the right or the left eye as the case might be 7 or more of the 10 trials and amphiocular if he used one eye only 5 or 6 times out of 10 trials. On the basis of the results obtained from the laterality index and the eyedness test two normal speaking groups of twenty individuals each were selected. One group was made up of individuals who indicated R on 98 percent or more of the items and who had always been right-handed and the second group of individuals who indicated L on 85 percent or more of the items and who had always been left-handed.

All members of the first group were right-eyed and 50 percent of the members of the second group were left-eyed. A third group consisted of twenty-three presumably right-handed adult stutterers who as a group showed ambidexterity on the laterality index. Fifty percent of them were left-eyed. The right-handed group had one female subject, the left-handed group three female subjects and the stuttering group none.

Results.—In a previous study (**12**) we determined that up to a certain amount of contraction there was an increase in action current frequency with an increase in intensity of mus-

Laterality Index

Note: Your hearty coöperation is desired. Please answer all questions carefully and conscientiously.

Date ——————————

Name —————————— Age —— Sex —— Nationality ——————

Are you right-handed or left-handed? Were you ever changed from left-handedness to right-handedness? If you were changed, how old were you at that time? Is either of your parents left-handed? Which one? Indicate, in the space below, the name, age, and hand-preference of each of your brothers and sisters. (Full names are not necessary; use initials if you prefer.)

Name of brother or sister	*Age*	*Hand-preference*

How old were you when you entered the first grade in school? Did you ever 'skip' a grade? Which one? If you ever had to repeat a grade, please answer these questions:

(*a*) Which grade was it?

(*b*) What was the reason for your failure to pass?

When you perform a manual act, one of your hands ordinarily does all, or almost all, of the work. With this thought in mind, you are to answer the questions below. Answer each one by drawing a circle around either 'R,' 'L,' or 'X.' If you almost always use the right hand for performing the act which is covered by a given question, draw a circle around the 'R' opposite that question. If you almost always use the left hand, draw a circle around the 'L.' If you have no particular choice (that is, if you use your hands interchangeably), draw a circle around 'X.' (Answer only those questions which are concerned with acts you have performed.) Do not encircle a letter until you are sure of the correct answer. If you are not sure observe youself perform the given act.

1. Which hand uses the powder puff?..... R L X
2. Which hand uses the needle in sewing?..... R L X
3. (When you are drying dishes, you hold the dish in one hand and wipe it with the other.) Which hand wipes the dishes?..... R L X
4. Which hand strops your razor?..... R L X
5. Which hand shaves your face?..... R L X

6. When you are standing with both feet together, which foot moves first when you start to fall forward?..... R L X
7. Which hand holds the thread when you thread a needle?..... R L X
8. Which hand uses the tooth brush?..... R L X
9. Which hand erases on paper?..... R L X
10. Which hand uses the can opener?..... R L X
11. Which hand does the stirring when you are mixing something?..... R L X
12. Which hand puts the letter into the envelope?..... R L X
13. Which hand uses a saw?..... R L X
14. Which hand holds your cigarette?..... R L X
15. Which hand scratches matches?..... R L X
16. (When you are washing dishes, you hold a dish in one hand and wash it with the other.) Which hand washes the dish?..... R L X
17. Which hand leads when you reach to a high shelf?..... R L X
18. Which hand would you use for lifting and carrying a cup level full of water?..... R L X
19. Which hand pulls the cork from a bottle?..... R L X
20. Which hand does most when you shuffle cards?..... R L X
21. Which hand combs your hair?..... R L X
22. Which hand uses wrenches?..... R L X
23. Which hand uses the dust cloth?..... R L X
24. Which hand drives the billiard cue?..... R L X
25. Which hand uses a hammer?..... R L X
26. Which hand do you use for drawing pictures?..... R L X
27. Which hand holds the knife when you whittle?..... R L X
28. Which hand uses the salt shaker?..... R L X
29. When you wash your hands, which hand rubs soap on the other?... R L X
30. Which hand wraps the tie around when you are tying it?..... R L X
31. Which hand uses a screw driver..... R L X
32. Which hand holds the fork when you eat with it?..... R L X
33. Which hand reaches to pick up a small object on the floor in front of you?..... R L X
34. Which hand does the most work when you tie a shoe-string?..... R L X
35. Which hand takes mail out of a box?..... R L X
36. Which hand holds a paper cup for drinking?..... R L X
37. Which hand deals the cards?..... R L X
38. Which hand uses scissors?..... R L X
39. Which hand cuts with the knife during eating?..... R L X
40. With which foot do you kick?..... R L X
41. Which hand swings a tennis racket?..... R L X
42. Which hand throws a ball?..... R L X
43. Which hand holds the knife when you slice bread?..... R L X
44. Which hand holds the knife when you peel fruit or vegetables?..... R L X
45. Which hand does the most work when you wring a cloth?..... R L X
46. Which hand wraps string around a package?..... R L X
47. Which hand manipulates the iron when you press?..... R L X
48. Which hand spreads butter on bread?..... R L X

TABLE I
RIGHT-HANDED NORMAL SPEAKERS

Subjects	Critical Point		Maximum Contraction		Critical Point/ Maximum Contraction	
	Right	Left	Right	Left	Right	Left
1	40	30	45	47	88.8	63.8
2	40	30	45	45	88.8	66.6
3	25	20	42	33	59.5	60.6
4	40	30	50	38	80.0	79.0
5	50	40	67	58	74.6	68.9
6	40	30	44	39	91.0	76.9
7	50	40	70	60	71.3	66.6
8	30	25	39	39	76.9	64.1
9	50	40	56	56	89.3	71.4
10	40	30	54	57	74.1	52.6
11	30	20	42	38	71.4	52.5
12	40	30	42	42	95.2	71.4
13	40	20	42	42	95.2	47.6
14	40	20	51	50	78.4	40.0
15	50	40	70	65	71.0	61.2
16	30	20	32	32	93.3	62.2
17	30	25	33	34	99.9	73.5
18	40	30	50	54	80.0	55.5
19	40	30	60	60	66.6	50.0
20	30	20	69	66	43.4	30.3
Mean	38.5	28.0	50.1	47.7	79.4	60.7

TABLE II
LEFT-HANDED NORMAL SPEAKERS

Subjects	Critical Point		Maximum Contraction		Critical Point/ Maximum Contraction	
	Right	Left	Right	Left	Right	Left
1	25	30	35	50	71.4	60.0
2	30	60	52	65	57.7	92.3
3	30	30	49	48	61.2	62.5
4	50	60	58	67	86.2	89.5
5	15	20	28	33	53.5	60.6
6	30	40	52	55	57.7	72.7
7	30	40	50	48	60.0	83.3
8	20	25	29	33	68.9	78.8
9	20	40	50	50	40.0	80.0
10	30	50	62	70	48.4	71.4
11	20	40	52	59	38.2	67.7
12	35	40	50	55	70.0	74.0
13	30	35	43	50	70.0	70.0
14	20	30	50	60	40.0	50.0
15	25	35	40	40	62.5	87.5
16	40	50	56	60	71.7	83.3
17	25	40	41	52	61.0	77.0
18	30	58	58	63	51.7	92.0
19	30	50	56	55	53.5	90.9
20	30	40	48	55	62.5	72.7
Mean	28.2	40.1	47.9	53.4	59.3	75.8

TABLE III

RIGHT-HANDED STUTTERERS

Subjects	Critical Point		Maximum Contraction		Critical Point/ Maximum Contraction	
	Right	Left	Right	Left	Right	Left
1	30	40	57	53	70.2	75.4
2	40	30	55	46	72.7	65.2
3	10	40	50	50	20.0	80.0
4	20	30	47	52	42.5	57.7
5	30	30	42	44	71.4	68.0
6	20	30	38	43	88.9	69.7
7	40	30	60	52	66.6	57.7
8	40	50	58	68	68.9	73.5
9	30	20	42	42	71.4	47.5
10	30	35	45	39	66.6	89.7
11	20	30	39	40	51.3	75.0
12	40	30	68	60	58.7	50.0
13	45	45	55	51	81.8	88.2
14	30	20	39	46	76.9	43.5
15	40	30	51	51	78.4	58.8
16	45	30	53	55	37.3	54.5
17	25	30	27	37	92.6	81.8
18	40	20	50	46	80.0	43.4
19	30	40	48	53	62.5	75.4
20	30	45	53	64	56.6	70.3
21	20	30	43	47	46.5	66.0
22	30	35	39	50	76.9	70.0
23	12	12	15	18	80.0	66.6
Mean	30.3	32.0	46.7	48.1	66.0	66.4

cular contraction. Beyond a certain amount of contraction the frequency of the action currents decreased (Fig. 2). The amount of contraction beyond which the action current frequency decreases is termed the critical point. In the present study it was found that for all normal speaking subjects with one exception (subject 3, Table II) this critical point was more for the preferred than for the non-preferred arm, *i.e.*, it was higher for the right arm in right-handed subjects and higher for the left arm in left-handed subjects. In a very few instances the action current frequency increased up to a certain amount of contraction, remained the same for an additional increase in intensity of contraction and then decreased for subsequent increases in contraction intensity. The critical point in these instances was taken as the point where the

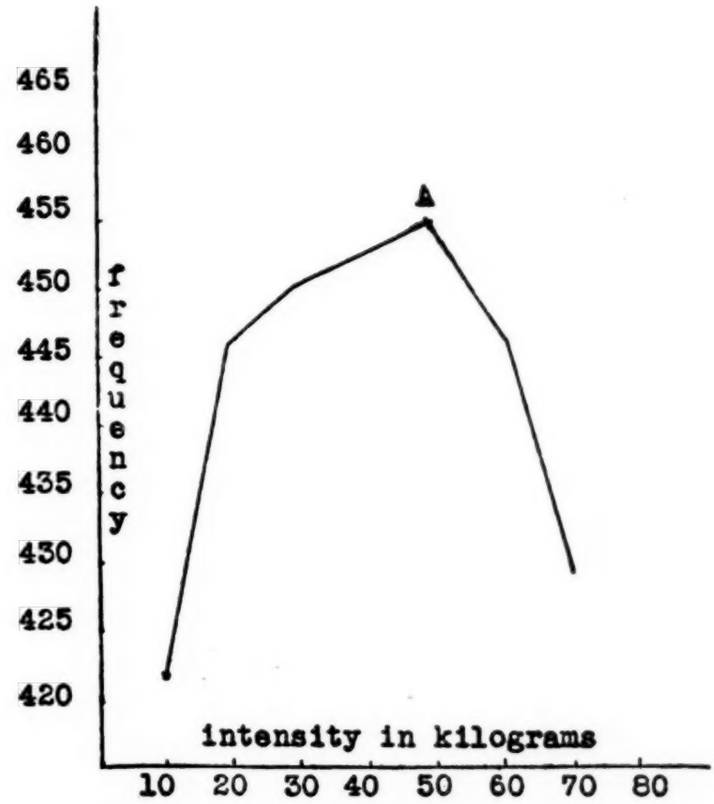

FIG. 2. A graph of the action current frequency readings for various intensities of muscular contraction. The point marked *A* is the critical point.

frequency ceased to increase (Fig. 3). In 52 percent of the stutterers the critical point was less for the right (the presumably preferred arm) than for the left arm and in 13 percent the critical point was the same for both arms (Table III).

It is to be noted from the tables that the mean critical point is greater for the preferred than for the non-preferred arm in normal speaking subjects and slightly greater for the left arm in stutterers. Although the differences are slight and possibly insignificant it is interesting that the mean maximum contraction is greater for the preferred than for the non-preferred arm in normal speakers while it is greater for the left arm in stutterers. A consideration of the data from the standpoint of the percentage of the maximum contraction at which the action current frequency decreased (critical point/maximum contraction) bears out the already noted trends.

Discussion.—This study corroborates others from this laboratory in finding a majority of presumably right-handed

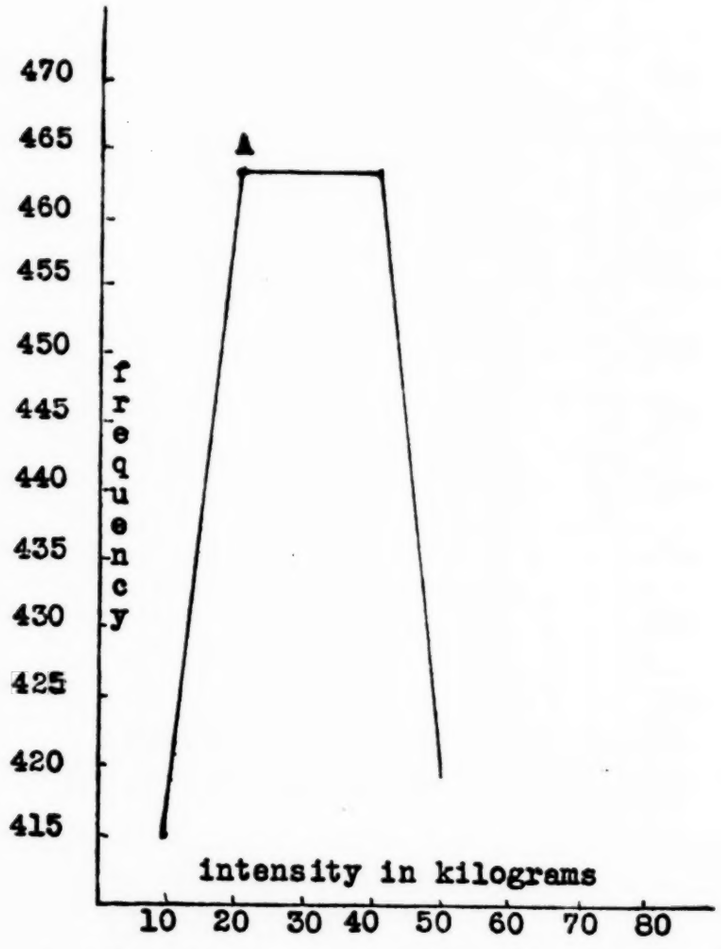

FIG. 3. A graph of the action current frequency readings for various intensities of muscular contraction. The point marked *A* was taken as the critical point.

stutterers similar in bilateral neuromuscular relationships to left-handed normal speakers (13), (14), (15), (16). Several workers (17), (18), (19), (20), (16) have reported a significantly larger percentage of left-handedness in stuttering than in normal speaking stocks. The meaning of these findings is not clear. Whether the factor of left-handedness itself or the factor of interference with the development of natural left-handedness is the one of primary etiological significance has not been determined. However it appears that either by hereditary or environmental forces the normal hierarchic relation of the two cerebral hemispheres has been disturbed to produce a bilaterality in the original lead control of the two hemispheres over the speech mechanism. The manifestations of a rivalry between the two hemispheres may be extremely varied.

During severe stuttering Travis (**16**) found that the patellar reflex response latency was greatly decreased. This indicated that during the act of stuttering the inhibitory control of the higher over the lower nervous levels was greatly reduced to permit a greater freedom of activity on the part of the lower levels. Herren's finding (**21**) of a striking reduction in the amplitude of certain tremors (10 to 12 per second) during stuttering bears out this concept of a blocking out of cortical control in stuttering. Jasper and Murray (**22**) discovered a high degree of dysintegration in the eye movements of stutterers during stuttering in oral reading that was indicative of marked disturbance in higher center control. The breakdown in the integrative activities of the higher levels is advertised in serious disturbances of the movements of the speech units (**23**), (**24**), (**25**), (**26**). In general these disturbances indicate the results of the inadequate control by the lower levels over the peripheral speech mechanism.

Other than assigning the majority of our stutterers to the left-handed group of normal speakers our findings are difficult to interpret. There are at least two questions to be answered: Why does the action current frequency decrease beyond a certain intensity of contraction? Why is the critical point greater in the preferred than in the non-preferred arm of normal speakers? In regard to the first question Richter (**27**) and Travis and Lindsley (**12**) found that as contraction approaches a certain intensity the action current waves become more regular and the small projections on the sides or in the troughs of the waves (Nebenzachen) disappear. This would result naturally in an apparent reduction in the number or frequency of the action currents. Richter (**27**) interpreted this to mean that the proprioceptive impulses which are one source of action currents, become synchronized somewhere in the neural pathway to the muscle. This synchronization is dependent upon the relationships between the times required for the various impulses to travel through the neural pathways, the time necessary for the motor impulses to cause new proprioceptive responses to be set up and the frequency of the proprioceptive impulses. The length of the neural pathways

would determine the frequency at which the action currents would synchronize. The variations noted in the synchronizing point in different individuals would bear out this conclusion. We have here then a plausible explanation of why action current frequency ceases to increase and even decreases beyond a certain intensity of muscular contraction.

In regard to the second question Lindsley (**28**) has found that changes in the activity of the cerebral cortex as produced by lesions, drugs and hypnosis produce the most significant changes in the action current frequency in any given neuromuscular unit under consideration. Any factor which reduced cortical activity reduced action current frequency. Inasmuch as the critical point is a function of both intensity of contraction and frequency of action currents we might have here an acceptable answer to the question of why the critical point is higher in the dominant arm. The dominant cerebral hemisphere in exerting a greater influence upon those muscles more directly innervated by it than does the non-dominant hemisphere exert upon those muscles similarly innervated, maintains the increase in action current frequency for a larger range of intensity of muscular contraction. Thus the greater critical point in the preferred arm would be an indication of greater control and activity of the dominant (contra-lateral) cerebral hemisphere. This being the case it would appear that in 52 percent of our stutterers the right cerebral hemisphere was the dominant one while in 13 percent, the two hemispheres were of equal dominance. Either of these conditions could conceivably lead to difficulty, the first because of the antagonism between the expressed and the inherent dominance and the second because of.the inherent equality between the two hemispheres. There is a significant number, 35 percent, of the stutterers who were normal as far as this study was concerned. Such a minority has been found in all of our studies. The only thing found to distinguish stutterers from normal speakers was the stuttering. This may mean either that our studies are not sufficiently analytical or that there are different kinds of stutterers.

Summary.—On the basis of history, a laterality index and

an eyedness test two groups of normal speakers, a left handed and a right handed group, were selected. A third group of subjects contained presumably right handed stutterers. For all but one of the normal speakers the critical point (the amount of muscular contraction beyond which the action current frequency decreases with additional increases in intensity of contraction) was greater in the preferred than in the non-preferred arm. For 52 percent of the stutterers the critical point was greater in the left than in the right arm while in 13 percent the critical point was the same for the two arms. It was thought that these findings supported the view that in many stutterers the stuttering is indicative of a disturbance in the normal hierarchic control of the two cerebral hemispheres over the peripheral speech mechanism.

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References

1. Adrian, E. D., The Basis of Sensation, N. Y., Norton, 1928.
2. ——, The impulses produced by sensory nerve endings, *J. Physiol.*, 1926, **61**, 49–72.
3. ——, The impulses produced by sensory nerve endings, Part 4, *J. Physiol.*, 1926, **62**, 33–51.
4. ——, The mechanism of the sense organs, *Physiol. Rev.*, 1930, **10**, 336–347.
5. Adrian, E. D., and Y. Zotterman, The impulses produced by sensory nerve endings, *J. Physiol.*, 1926, **61**, 151–171.
6. Adrian, E. D., and K. Umrath, The impulse discharge from the Pacinian corpuscle, *J. Physiol.*, 1929, **68**, 139–154.
7. Adrian, E. D., and F. J. J. Buytendijk, Potential changes in the isolated brain stem of the goldfish, *J. Physiol.*, 1931, **71**, 121–135.
8. Adrian, E. D., Potential changes in the isolated nervous system of *Dystiscus Marginalis*, J. Physiol., 1931, **72**, 132–151.
9. Bishop, G. H., and S. H. Bartley, Electrical activity of the cerebral cortex as compared to the action potential of excised nerve, *Proc. Soc. Exp. Biol. and Med.*, 1932, **29**, 698–699.
10. Bartley, S. H., and G. H. Bishop, Cortical response to stimulation of the optic nerve, *Proc. Exp. Biol. and Med.*, 1932, **29**, 775–777.
11. Parson, B. S., *Left-handedness*. N. Y., Macmillan, 1924.
12. Travis, L. E., and D. B. Lindsley, The relation of frequency and extent of action currents to intensity of muscular contraction, *J. Exp. Psychol.*, 1931, **14**, 359–381.
13. Orton, S. T., and L. E. Travis, Studies in stuttering. IV. Studies of action currents in stutterers. *Arch. Neurol. and Psychiat.*, 1929, **21**, 61–68.
14. Travis, L. E., and R. Y. Herren, Studies in stuttering. V. A study of simultaneous antitropic movements of the hands of stutterers. *Arch. Neurol. and Psychiat.*, 1929, **22**, 487–494.

15. JASPER, H. H., A laboratory study of diagnostic indices of bilateral neuro-muscular organization in stutterers and normal speakers, *Psychol. Monog.*, 1932, **43**, 72–174. Univ. of Iowa Studies in Psychol., No. XV.
16. TRAVIS, L. E., *Speech Pathology*, N. Y., Appleton, 1931.
17. BALLARD, P. B., Sinistrality and speech, *J. Exp. Ped.*, 1912, **1**, 298–310.
18. SCRIPTURE, M. K., GLOGAU, O., AND A. H. DEBRA, Left-handedness as an etiological factor in speech defects, *Laryngoscope*, 1917, **27**, 157–169.
19. CLAIBORNE, J. H., Stuttering relieved by reversal of manual dexterity, *New York Med. Jr.*, 1917, **105**, 577–581, 619–621.
20. SACHS, M. W., Zur Aetiologie des Stötterns, *Klin. Wochenschr.*, 1924, **37**, 113.
21. HERREN, R. Y., The relation of stuttering and alcohol to certain tremor rates, *J. Exp. Psychol.*, 1932, **15**, 87–96.
22. JASPER, H. H., AND E. MURRAY, A study of the eye-movements of stutterers during oral reading, *J. Exp. Psychol.*, 1932, **15**, 528–538.
23. TRAVIS, L. E., Studies in stuttering. I. Dysintegration of the breathing movements during stuttering. *Arch. Neurol. and Psychiat.*, 1927, **18**, 673–690.
24. ——, Studies in stuttering. II. Photographic studies of the voice in stuttering. *Arch. Neurol. and Psychiat.*, 1927, **18**, 998–1014.
25. FOSSLER, H. R., Disturbances in breathing during stuttering, *Psychol. Monog.*, 1930, **40**, 1–32. Univ. of Iowa Studies in Psychol., No. XIII.
26. BRYNGELSON, B., A photophonographic analysis of the vocal disturbances in stuttering, *Psychol. Monog.*, 1932, **43**, 1–30. Univ. of Iowa Studies in Psychol., Vol. XV.
27. RICHTER, C. P., On the interpretation of the electro-myogram from voluntary and reflex contractions, *Quart. J. Exp. Physiol.*, 1928, **18**, 54–77.
28. LINDSLEY, D. B., Some neuro-physiological sources of action current frequencies, *Psychol. Monog.*, Univ. of Iowa Studies in Clinical Psychology, Vol. I in press.

THE SENSORY FUNCTION OF THE NON-PREFERRED HAND

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I. *A.* Problem

Whenever handedness is mentioned, reference is made to motor preference. A right-handed person is one who uses his right hand for all unimanual activities; a left-handed person is one who uses his left hand for all unimanual activities; an ambidexterous individual either uses both hands equally well or uses one hand for some, the other hand for other, activities. And the 'activities' referred to are writing, eating, hammering, throwing, batting, and such motor performances. The fact that the human being's actions may be classified as motor or sensory has apparently been overlooked. Which hand does a man use to feel the straightness of the part in his hair? With which hand does he feel over his desk when searching in the dark for his fountain pen? In other words, when for some reason he is deprived of the use of a sense organ and must substitute a hand for this sense organ, which hand does he prefer?

An experiment conducted in 1928 on the subject of the psychology of the blind brought this problem to the attention of the writer. The subject of the earlier experiment read Braille characters with each hand separately, and with each hand in each of the directions left and right. The results indicated that for that particular subject, a right-handed person, the left hand was the superior in reading Braille.[1] An ex-

[1] This result is not surprizing in the light of previous work on reading of blind script. P. Villey, Psychologie de la lecture tactile, *Jour. de Psy.*, 1931, **28**, p. 237, in summarizing the present status of hand preference in reading, states that psychologists are not in agreement upon the relative ability of the two index fingers in reading Braille; that the Germans present statistics to support the superiority of the left hand, while the Americans show by statistics that the majority of the best readers use the right hand. He also remarks pertinently, "Gardons nous de trancher une controverse qui peut avoir son origine dans des traditions locales." In the United States, where the

planation of this surprizing result lay in the assumption of a sensory preference for the non-preferred motor hand. Reading Braille characters with the fingers is undoubtedly a sensory activity of the fingers.

The present experiment was conducted in an attempt to test this hypothesis of a sensory preference for the non-preferred motor hand. It consists of two parts.

B. Method

1. Repetition of Braille Reading

The experiment in reading Braille is being repeated with three subjects, one right-handed, one left-handed, and one ambidexterous. As this experiment is still in progress the results will be reported separately at a later date.

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majority of the best readers are numbered among the right-handed readers, schools for the blind teach right-handed reading.

Several objections have been brought against the previous work, all except one of which are probably due to the inability of a practical man, concerned with practical problems of the blind, to appreciate a theoretical psychological problem (Swift, *Outlook for the Blind*, 1930, XXIII, 4). The criticism excepted is that results from a seeing subject can not be applied to the blind. On this point attention is called to an experiment conducted by Renshaw, Wherry, and Newlin, with four classes of subjects—blind and seeing adults, and blind and seeing children. It seems that their results lead to a conclusion quite different from the one they draw, namely: "Our results call into question conclusions regarding the teaching of the blind based upon experimentation upon blindfolded adult subjects." (Renshaw, Wherry, and Newlin, Cutaneous localization in congenitally blind versus seeing children and adults, *Jr. of Genetic Psy.*, 1930, **28**.) Their results show the following points:

a. The blindfolded, seeing adult localizes cutaneously as does the blind child:
(1) The blindfolded, seeing adult must use tactual-kinesthetic localization: the use of the visual localizing habits is precluded by the blindfold.
(2) The blind child must use tactual-kinesthetic localization: he has no visual habits.

b. There is little difference in accuracy of tactual-kinesthetic localization for the two groups, blind children and seeing adults (see graph, p. 244). The learning curves of the blind children and the blindfolded, seeing adults are similar, and different from those of the blind adults and seeing children: the decided negative acceleration in the latter curves is conspicuously missing in the former.

The localizations of the blind children and the seeing adults are more similar than those of the blind children and blind adults (see graph, p. 244). The difference in accuracy between the blind children and blind adults is due to greater exercise of tactual-kinesthetic localizing habits by adults—a practice lacking entirely in seeing adults—and would be still greater in a habit intensively trained (as Braille reading).

From these data the conclusion seems evident, that:

c. The best subjects for studying methods of teaching the blind anything involving tactual-kinesthetic coördination are untrained, blind children; good substitutes (better than blind adult persons) because of their similarity to blind children in method of and experience in localizing are blindfolded, seeing adults.

2. Formboard

The second experiment consisted in having a large number of normal adults, selected at random from the college population, replace the blocks in the Goddard formboard when blindfolded. The subject was blindfolded in an outer room and lead to the table on which the formboard rested, the figures placed in regular order about the three far sides of the board. The subject was told that before him there was a board which had ten depressions in its surface; that about the edges of the board were ten blocks which fitted into the depressions; and that he was to place the blocks in the depressions as accurately as possible. No directions as to method to be used were given; the only restriction was that when a block had once been picked up, it must be placed before another was touched.

The activities involved in placing the blocks in the board are four: picking up a block, feeling the shape of the block, feeling the shapes of the holes in the board, and placing the block in the proper hole. Picking up and placing are chiefly motor; feeling shape, whether of block or of depression, is chiefly sensory. If the subject is not deprived of the use of his eyes by the blindfold he simply looks at the board, looks at the blocks, chooses a block, and places it in the proper depression. When blindfolded he substitutes his hands for his eyes in determining the shapes of the blocks and of the depressions. The present problem was to determine which hand he used for this sensory function.

3. Eye Dominance

In addition to the working of the formboard, each subject was tested for eye dominance. He was given a piece of typewriting paper with an inch hole in the center, and asked to look through this hole at a thumb tack four feet from him while holding both eyes open. When he said that he saw the tack he was told to close his eyes alternately; if he saw the tack when his left eye was closed, he showed right eye dominance, and vice versa.[2]

II. Results

A. Formboard

In order to have a check against preferential sensory use, the subjects were classified according to their preferential motor use. Each subject was asked which hand he used in: writing, eating, throwing, batting, hammering, playing tennis. If every activity named was performed with the right hand, the subject was called *R*. If every activity named was performed with the left hand, or writing or eating only was performed with the right hand, the subject was called *L*. Eating or writing (not both) was allowed because of the great amount of social pressure which is brought to bear upon a left-handed person in these activities. If the subject did not belong in either of these two classes he was called *A*, with the result

[2] This method is described by N. V. Scheidemann, A simple test for ocular dominance, *Amer. J. Psychol.*, 1931, **43**, 126.

that the *A*'s are an exceedingly heterogeneous group and cannot be treated as similar.[3]

The data considered for sensory function are those of feeling the depressions only, and do not include feeling the block. For the great majority of the subjects, picking up the block involved enough cutaneous sensation to give the shape; few of the subjects felt the block. The most difficult portion of the performance was without doubt the determination of the shape of the holes. This is to be expected, when we consider that the adult has had a great deal of experience in picking up and holding variously shaped objects; but few have had necessity or opportunity for feeling concave surfaces.

Table I shows that no left-handed subject used his left

TABLE I

HAND USED FOR FEELING HOLES *

Motor preference	All *R*, or more *R* than *L*			½ each *R* and *L*	All *L*, or more *L* than *R*		
	All *R*	More *R* than *L*	*R*, some *B*, no *L*		*L*, some *B*, no *R*	More *L* than *R*	All *L*
Left 29	14 48.3%	11 37.9%	1 3.5%	0	0	3 10.3%	0
Total		26 89.7%		0		3 10.3%	
Ambi. 38	13 34.2%	11 29.0%	1 2.7%	4 10.5%	1 2.6%	4 10.5%	4 10.5%
Total		25 65.9%		4 10.5%		9 23.6%	
Right 37	0	3 8.1%	0	2 5.4%	3 8.1%	13 35.1%	16 43.3%
Total		3 8.1%		2 5.4%		32 86.5%	

* In this and the following tables *R* = right hand, *L* = left hand, and *B* = both hands.

hand to feel the shapes of all the holes; 48.3 percent of the *L* subjects used the right hand entirely for feeling; 37.9 percent used the right hand more frequently than the left; 3.5 percent

[3] Attention is called to the fact that this practical criterion of selection insures the use of pure types, a classification not obtained by the use of more complicated tests such as those of Rife or Downey. As the point of emphasis here is the hand actually used by the subject in specific and usual manual performances, the whole pedal question is disregarded.

used the right hand alone, and both hands together, but not the left hand alone; and only 10.3 percent used the left hand more frequently than the right. In other words, left-handed persons used the right hand for feeling. Of the right-handed subjects, 43.3 percent used the left hand alone, 35.1 percent used the left hand more than the right; 8.1 percent used the left hand alone and both hands together; 5.4 percent used the two hands an equal number of times; none used the right hand entirely; and but 8.1 percent used the right more frequently than the left. This is shown more clearly by the totals, in which the right, more right than left, and right and both hands are pooled against the left, more left than right, and left and both hands. Then it is seen that 89.7 percent of the *L* subjects used the right hand preponderantly as against 10.3 percent who used the left hand most; and 86.5 percent of the *R* subjects used the left hand preponderantly as against 8.1 percent who used the right hand most.

Table II gives the data for the hand used in picking up blocks. It will be noted from Table II that of the *L* subjects 41.3 percent used the left hand more than the right; 17.3 percent used the right hand more than the left; and 41.3 percent

TABLE II

HAND USED FOR PICKING UP BLOCKS

Motor preference	All *L* or more *L* than *R*		½ each *L* and *R*	All *R* or more *R* than *L*	
	All *L*	More *L* than *R*		More *R* than *L*	All *R*
Left 29	1	11	12	4	1
	3.5%	37.9%	41.3%	13.8%	3.5%
Total		12	12	5	
		41.3%	41.3%	17.3% *	
Ambi. 38	1	11	16	8	2
	2.7%	29.0%	42.1%	21.0%	5.2%
Total		12	16	10	
		31.7%	42.1%	26.2%	
Right 37	0	9	11	16	1
		24.3%	29.7%	43.3%	2.7%
Total		9	11	17	
		24.3%	29.7%	46.0%	

* The percentages in this row total 99.9, due to the fact that the percentages were not carried beyond the first decimal place.

used the two hands equally often. Of the *R* subjects, 46.0 percent used the right hand more than the left, 24.3 percent used the left hand more than the right, and 29.7 percent used the two hands equally often. The reason for the large percent of times the two hands were used equally often is that the blocks were placed about the board, three to the right, three to the left, and four across the board away from the subject. Most subjects picked those on the left with the left hand; those on the right with the right hand; and those on the far side were divided between the two hands. Of the 104 subjects but six used the same hand in reaching for all ten blocks. It will be noticed that a larger number of the *L*'s used the left hand more frequently than the right (37.9 percent) than those who used the right hand more frequently than the left (13.8 percent). Conversely, more of the *R*'s used the right hand more frequently than the left (43.5 percent) than the left hand more frequently than the right (24.3 percent). The *L*'s showed a tendency to use the left hand for lifting the blocks to the left and also on the far side; the *R*'s used the right hand for those on the right and on the far side.

Placing the blocks in the depressions appeared to be simple for most of the subjects. More than half placed the blocks with both hands, showing no visible preference for one over the other. Table III shows the hands used in placing the blocks.

TABLE III

HAND USED IN PLACING BLOCKS

Motor preference	All *L*	*L* and *B*	All *B*	*B*, *R*, *L*	*R* and *B*	All *R*
Left 29	0	4 13.8%	17 58.6%	3 10.3%	4 13.8%	1 3.5%
Ambi. 38	1 2.7%	6 15.8%	20 52.6%	5 13.1%	5 13.1%	1 2.7%
Right 37	0	4 10.8%	22 59.5%	4 10.8%	7 18.9%	0

The performance of the typical subject in the formboard test may be described as follows. The right-handed individual picked up first with his right hand the block that was nearest to him on the right side of the board. He held it in

his right hand, apparently without sensorily exploring it, and felt over the board with his left hand. His left hand would stop in a certain hole; his right hand carry the block to that hole; and both hands fit the block in. If the depression chosen were not the right one, the right hand took the block back to the edge of the table, holding it there while the left hand continued its search over the board. The right hand picked up the three blocks on the right side, and probably the four on the far side also; the left hand continued to feel the cavities. The left hand would then pick up a block on the left, pass it to the right hand, and continue the search on the board. That the feeling hand is not the hand-that-does-not-pick-up-block is clear from a study of Tables I and II. This fact was also, of course, obvious to the experimenter who observed the procedure. The performance of the typical left-handed subject was the exact opposite of that of the right-handed person.

The data show that the right-handed person used his left hand, and the left-handed person used his right hand, in the sensory function of determining the shapes of the depressions.

B. Eye Dominance

Of the 104 subjects, 70.3 percent showed right eye dominance, 28.8 percent showed left eye dominance, and .9 percent showed no eye dominance. It is interesting to note that the percents of the total number taken together, regardless of hand preference, are about the same as the percents of the right- and left-handed and ambidexterous groups. This agrees very well with Parsons' statement that 30 percent of all individuals

TABLE IV

EYE DOMINANCE AND HANDEDNESS

Motor preference	Dominant eye		
	Left	Right	Neither
Left 29	9 31.0%	19 65.5%	1 3.5%
Right 37	11 29.7%	26 70.3%	0
Ambi. 38	10 26.3%	28 73.7%	0

are left-eyed and 70 percent are right-eyed.[4] It does not, however, agree with the contention of Parsons and others that eyedness and handedness correlate highly.

Scheidemann[5] says: "In trying to discover the native hand-dominance of this group, each child was given a test for eyedness which was considered the criterional index of handedness, not with the conviction so unequivocally held by Parsons that eyedness determines handedness; but rather with the assumption that since eye-dominance and hand-dominance show a very high positive relationship, both may be determined by a common cause." Other writers[6] express the same idea: "This would support the theory that we are physiologically unilateral—*i.e.*, sinistrals tend to be left monocular and dextrals tend to be right monocular. There are, however, many exceptions." In reporting on about 1,000 cases, Mills[7] says that 76 percent were pure dextrals (right-handed and right-eyed), 9.3 percent pure sinistrals (left-handed and left-eyed), 13 percent crossed dextrals (right-handed and left-eyed), and 1.7 percent crossed sinistrals (left-handed and right-eyed). This means that of Mills' 1,000 subjects there were 5.8 times as many pure dextrals as crossed dextrals; and 5.4 times as many pure sinistrals as crossed sinistrals. Of the subjects in the present experiment there are 2.4 times as many pure as crossed dextrals; and .47 times as many pure as crossed sinistrals. These data indicate that handedness connot possibly be determined by dominance of eye; for the majority of the subjects, regardless of hand preference, were right-eyed. It is difficult to consider that these 104 subjects constitute a group peculiar in their eyedness, as they were chosen at random from a large student body.

[4] Parsons, B. S., Left-handedness, New York, Macmillan, 1924.

[5] Scheidemann, N. V., A study of the handedness of some left-handed writers, *Genet. Psy. Mon.*, 1930, **38**, p. 511.

[6] Coons and Mathias, Eye and hand preference tendencies, *J. Genet. Psychol.*, 1928, **35**, 629–32.

[7] Mills, L., Eyedness and handedness, *Amer. J. Ophth.*, 1925, **8**, 933–941.

III. Discussion

The results of this experiment suggest that the non-preferred motor hand is preferred for sensory activity, and that eyedness is not related to handedness.

Several explanations occur for the preferential use as a sensory organ of the non-preferred motor hand. In order to avoid the use of cumbersome phrases, the right-handed individual will be discussed, the preferred motor hand being called right and the preferred sensory hand called left. 1. During the form-board experiment the left hand was used as sensory because it was free from motor use; as the preferred hand, the right, was used for the motor function, the remaining hand performed the remaining tasks. 2. The left hand is preferred for the sensory function because of its sensitiveness, its freedom from the toughness which characterizes the more frequently used right hand. 3. The left hand is preferred for sensory functions in the same sense and to the same extent that the right hand is preferred for motor functions.

It might be contended that the harder part of the task was the motor, that of holding and placing the block; that therefore the right hand performed this duty, leaving the lesser one of feeling to the left hand. But this possibility is ruled out upon consideration of the actual method used by the subjects. The right hand was in most cases idle; it rested on the edge of the board with the block in it while the left hand moved actively over the depressions. The muscular activity of the arm in moving the hand about was decidedly the most arduous work. It was secondary only to the precision of judging the shapes of the holes. If the motor action were the decisive factor in choice of hand, undoubtedly the right hand would have been used as the feeler. The hand used for feeling is not the hand unused for reaching; it is in some cases and not in others. 46.0 percent of the right-handed subjects used the right hand in picking up blocks; 46.0 percent, then, had a free left hand for feeling, But the proportion who used the left hand for feeling was 86.5 percent. This means that 40.5 percent of them must have picked up the block with the left hand and passed it to the right hand, thus freeing the left hand for

the sensory function. Stated another way, on the average four of the ten blocks were reached for by the left hand and passed to the right.

Perhaps the left hand is superior to the right in sensory capacity, and this superiority is the result of its softness, acuteness. The left hands of most right-handed persons are more delicate—less callous—than the right hands. Here we may refer again to the experience of blind script readers. Of them Villey says:[8] "On s'est étonné de constater, dans l'enquête faite au Etats-Unis, que les doigts calleus des ouvriers vanniers et choisiers n'étaient pas moins aptes à la lecture tactile que ceux des intellectuels." The reading finger of the blind person soon becomes toughened, but does not lose its sensitiveness because of this fact. A peculiar case which appeared in the present experiment may throw some light on this question. One of the subjects, who was classed as left-handed, has this history: while a small child his right arm was pulled from the socket, and subsequently operated upon several times. For many years he had no use of the right arm, so learned to perform all activities with his left hand. His father insists that the boy was naturally right-handed, becoming left-handed only through pressure of circumstances. He is one of the three left-handed subjects who used the left hand more frequently than the right in feeling the depressions. He used the right hand once, the left hand nine times, in the sensory capacity; in this he behaved as the right-handed subjects. He showed no eye dominance. If it is true that he is—or was—naturally right-handed, but performs all motor activities with the left hand through training, his performance with the formboard would indicate that sensory preference is determined in some manner other than by freedom from motor use.

A consideration of some of the cases classed as ambidexterous assists in the clarification of the question. Twenty persons so classed were at one time left-handed, but at the time of the test performed some motor activities with the right hand; for example, one throws, bats, hammers, and plays tennis with the left hand, and has written and eaten since the

[8] *Op. cit.*, p. 221.

age of ten with the right hand. He used the right hand entirely in feeling over the formboard.

If the preferential use of one hand as a sensory organ were the result of its softness, we would expect that the non-motor hand would be so used regardless of the original tendency of the persons. The trained use of the left-handed person's right hand in motor functions, however, apparently does not interfere with its use in the sensory capacity. (See Table V.)

TABLE V

SENSORY PREFERENCE OF AMBIS WHO WERE AT ONE TIME LEFT-HANDED 20

Right	½ each *R* and *L*	Left
15	1	4
75%	5%	20%

Of 29 subjects called left-handed, seven either write or eat with the right hand. Of these, six show right-hand sensory preference, one shows left-hand sensory preference. The proportions of those showing right-hand sensory preference is almost exactly the same for the two sub-groups of the left-handed class, as shown in Table VI.

TABLE VI

SENSORY PREFERENCE OF THE LEFT-HANDED GROUP

Sub-group	Sensory hand preference	
	Right	Left
Entirely left 22	20	2
	90.9%	9.1%
Left except eating or writing 7	6	1
	85.7%	14.3%
Total L's 29	26	3
	89.7%	10.3%

A similar experiment with children who are old enough to show decided motor preference, yet young enough to be relatively free from the results of training, would probably answer this question.

The most probable explanation for the preference of the non-preferred motor hand in sensory functions is that whatever causes handedness in the sense of motor preference also causes handedness in the sense of sensory preference. The sensory preference is not the result of motor preference (as

shown above), but is a concurrent and causally independent phenomenon.

IV. Summary

In order to test the hypothesis of sensory preference for the non-preferred motor hand, these experiments were performed: three groups of persons, right-handed, left-handed, and ambidexterous, replaced the blocks in the Goddard formboard when blindfolded. As this is related to the subject of sidedness, each subject was also tested for eye dominance. The results are:

1. The right-handed subjects show preference for the left hand in feeling the shapes of the depressions in the Goddard formboard.

2. The left-handed subjects show preference for the right hand in feeling the shapes of the depressions in the Goddard formboard.

3. Left-handed subjects who have been trained to perform some motor activities with the right hand show the same preference for the right hand in feeling the shapes of the depressions.

4. 70.3 percent of all subjects showed right eye dominance, with no relationship between eyedness and motor hand preference.

5. The results of the experiment are interpreted to mean that the pronounced sensory preference shown for the non-preferred motor hand is not the result of, but is causally independent of, the motor preference.

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EFFECT OF COMPLETE STRIATE MUSCLE PARALYSIS UPON THE LEARNING PROCESS

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Psychology has long been vexed by a persistent controversy concerning the fundamental nature of the learning process. One group of psychologists has held to the *intra-cerebral* view that the trial-and-error process of learning is represented physiologically by a sort of 'battledore and shuttlecock' process which is limited entirely to the cerebrum. This theory is also implied in the writings of most physiologists and neurologists. Other psychologists have suggested a contrasting *peripheral* view, to the effect that learning of necessity involves an effector response. The assumption usually made is that the response sets up proprioceptive impulses which play some essential part in bringing about a concatenation of reflex arcs constituting the total response; however, it has also been suggested that some purely motor element is essential to consciousness and therefore to learning.

Various *indirect* methods have been employed in an attempt to solve this problem. Of these, one is the attempt to measure sub-vocal speech during thinking by obtaining records of movements of the throat, larynx, tongue and lips. Such investigations have been carried out by Thorson (**17**), Clark (**3**), and others, and the results in general seem to confirm William James' observation (**12**) that it is very hard to think 'bubble' with the mouth open. A more accurate method of investigating the motor responses occurring concurrently with mental states has been used by Jacobson, (**9**, **10**, **11**), who was able to show that imagining a given movement was always associated with electrical changes in the appropriate body part. Furthermore, Jacobson has shown in more recent work that various substitute responses may occur if the appropriate response is impossible. (It must be noted that this

work does not prove that the motor response is an *essential* component of the learning process.) Experiments in educational psychology would also appear to support the motor hypothesis, as they show that making the response speeds up the learning process (*i.e.*, active recitation of the particular response (**5**) is more efficient than passive learning).

The intra-cerebral view finds indirect support in evidence which appears to be of about equal value. Thus Lashley was able to demonstrate that learning can be retained in spite of the extirpation of the motor areas controlling the movements originally made, and that complicated serial habits may be formed and retained after extensive destruction of nerve tracts in the spinal cord and of areas in the cerebellum, both of which procedures should have affected adversely the number and sequence of the proprioceptive and motor impulses. These facts are opposed to any theory of learning based on the integration of concatenated reflex arcs. Evidence from pathology has also been interpreted as favoring the intra-cerebral view: thus, Dana (**4**) states that "a person continues to . . . think perfectly well after the larynx has been removed or paralyzed, and also when there is a *complete* muscular paralysis!"[1] Head's observations on deaf, dumb, and paralyzed patients still successfully playing chess may be taken in the same regard. The vast amount of evidence which favors the central theory of emotions (**6**) lends a certain dignity to the central view of thinking.

These indirect methods have failed to yield conclusive evidence as to the truth or fallacy of the controversial theories of learning, and indeed there appears to be little hope of their ever doing so.

Heretofore it has been assumed that direct experimentation, and therefore an unequivocal answer to the problem is impossible, because under *complete* motor paralysis it is impossible to demonstrate the effects of learning.

The present experiments offer *direct* demonstration of the solution of this problem through the use of the drug curare, which paralyzes the striate musculature by acting upon the

[1] Italics and exclamation point ours.

myoneural junction [2] to prevent the passage of nerve impulses from the motor neuron to the muscle fibre. Inasmuch as this effect can be removed more or less at the option of the experimenter, it is obvious that the learning situation may be presented under curare, followed by tests for the effect of learning after the drug is neutralized.

Curare has been known to the civilized world since 1595, and its properties have been fairly well understood since the studies of Claude Bernard in 1857. The drug paralyzes only skeletal muscles (**16**), leaving the unstriped musculature unaffected or only slightly influenced. The receptors and reflex centers of the spinal cord and midbrain can be shown to be functioning while the animal is completely paralyzed except in a ligated limb. Its lethal properties are attributable only to the paralysis of the respiratory muscles, death being due to asphyxia. Many of the secondary effects, such as increased acidity of the blood, are probably to be ascribed to reduced aeration in cases where animals have been kept alive under the drug. No studies so far have proven the persistence of cortical activity, but our experiments give definite proof that this also persists.

Experimental Procedures [3]

In our studies of the learning process in curarized animals we have employed three kinds of learning situations, with certain variations which will be described in detail later. The first situation involves the acquisition of an adaptive response to pain. A conditioned stimulus is presented, followed by severe faradic shocks; the response includes leaping from the grid and avoiding the experimental situation.

In a second situation the conditioning of a simple reflex response to pain is involved. The flexion of the leg in response to faradic shock is to be associated with a conditioned stimulus.

The third learning activity was employed as a control for

[2] For a discussion of the theories as to the exact locus of the action of curare, see Sollman (**16**).

[3] We wish to acknowledge the generous assistance of Mr. E. T. Katzoff and Mr. Harry Silverman in conducting these experiments.

the other two, and involved the conditioning of a smooth muscle response (pupillary dilatation to pain)—it should be emphasized that smooth muscles are never paralyzed by normal doses of curare. Only cats and dogs have been used in the experiments reported.

Apparatus and Technique

The apparatus used in these experiments was relatively simple. For the first experiments, on the learning of an adaptive reaction, a grill of wrought iron, 18 × 30″, with sides 12″ high, was constructed, as shown in Fig. 1. The grill was made of 1/2″ strips of iron 1/2″ apart, connected by bakelite strips to prevent short-circuiting. Tetanizing shocks were given from an induction coil receiving 27½ volts through a transformer from lighting current. The same apparatus was used for the observations on the conditioned pupillary reaction.

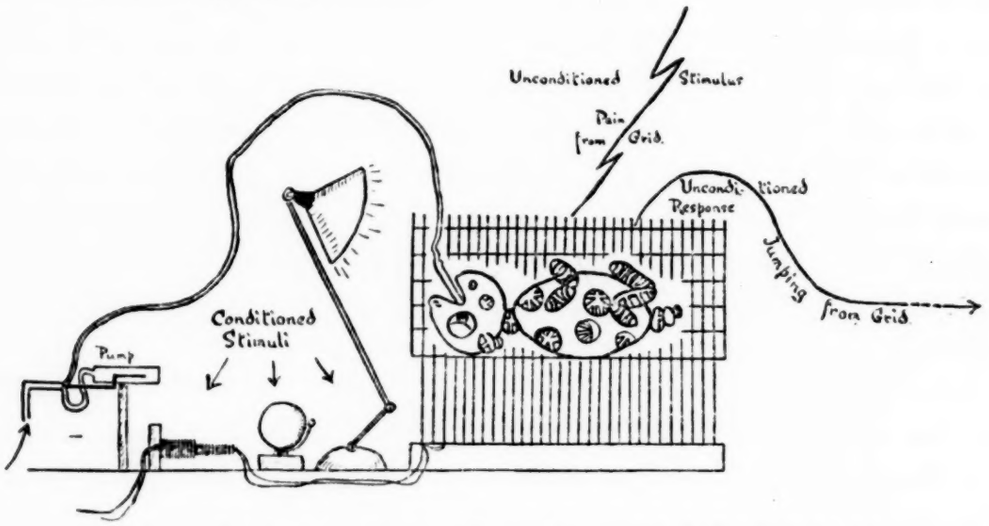

Fig. 1. Set for adaptive reaction. Buzzer (3), bell (2), light (1).

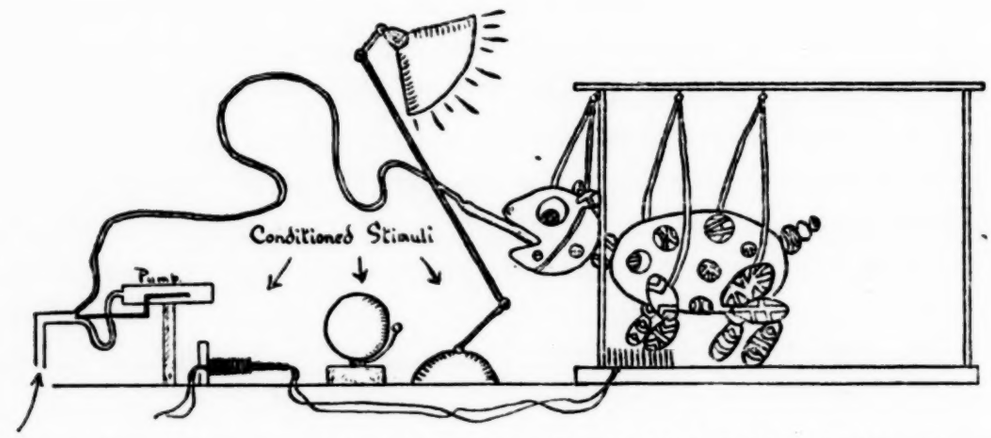

Fig. 2. Set for simple conditioned response. Buzzer (3), bell (2), light (1). Unconditioned stimulus—Pain from grid. Unconditioned response—Lifting left fore foot.

For the conditioning of a simple leg flexion, a modified Pavlov holder, shown in Fig. 2, was used. In this apparatus the animal was suspended from straps which held him in the desired position, his head being kept in a fixed position by stocks. A grill was placed under each forepaw, but only one was used in any given experiment.

As conditioned stimuli we used a 50-watt lamp flashed into the animal's eyes, a bell sounded immediately after the light, and the buzzer of the induction coil. The presentation of stimuli was thus: light 9 sec, bell last 7 sec, buzzer last 2 sec. Thus the light and bell, according to Anrep, are delayed conditioned stimuli; the buzzer is a simultaneous conditioned stimulus.

In the use of curare it is necessary that the experimental animal be kept alive by artificial respiration. In this case we inserted a tracheal cannula by way of the mouth, through which oxygen or, in some cases, compressed air, was administered. An interrupter was placed in the circuit so that the inflow of gas corresponded to normal inspiration. Outflow occurred around the cannula, which did not fit the trachea snugly.

To avoid the depressant effects of the usual anesthetics on the central nervous system, we decided to dispense with them entirely in this experiment. The animal was given the injection of curare proper for his body weight (we used 4.5 mgm per kilo subcutaneously) and the experimenters then waited until muscular weakness set in, but before respiratory paralysis, to insert the cannula. When we desired to terminate the experiment, injections of physostigmine and sodium bicarbonate were used to neutralize the curare.

Experiment 1.—This experiment was devised to test the possibility of learning an adaptive response to pain under curare paralysis. A definite series of tests before and after the training series was employed to determine the extent of learning. These were as follows: (1) animal placed on chair, no additional stimuli given, time to jump recorded; (2) response to chair, followed after five seconds by buzzer for two seconds; (3) response to chair, followed five seconds later by light for nine seconds, bell seven seconds, buzzer two seconds; (4) animal placed in grill, no additional stimuli, time to jump recorded; (5) response to grill plus buzzer (without shock); (6) response to grill plus light, bell and buzzer (without shock). Relative strength of the response was rated on the basis of speed of jumping (maximum time allowed, 30 seconds) and violence (rated by experimenters on a scale from zero to ten).

This series of tests was made on each animal before injection of curare. After the animal was completely paralyzed, as diagnosed by absence of muscle twitches, gag reflex, and the corneal eye-lid reflex, he was placed in the apparatus and a training series administered. The usual training series con-

sisted of thirty applications of the conditioned and unconditioned stimuli, although the exact number fluctuated somewhat as a result of difficulties with individual animals. Stimuli were not given after the animal appeared to be recovering. After complete recovery the same series of tests was repeated to determine the effect of the training.

In seven control animals, five cats and two dogs, which were conditioned without curare, learning invariably occurred in *three* trials or less. After this was proven, the second series of tests was given to determine the amount of irradiation of the conditioned stimuli. The same series was used on these animals to test retention after varying lengths of time.

Both control dogs showed marked retention after 24 hours. Indeed, both showed marked retention one week after the original reinforcements, although they had been tested regularly to the conditioned without the unconditioned stimuli. Of the cats, two leaped from the grill 24 hours after conditioning. The other three showed signs of uneasiness in the grill but did not jump. Tests after more than 24 hours, it may be noted, show little or no waning in strength. Indeed 'experimental extinction' by non-reinforcement seemed to increase the strength and speed of the response!

The experimental animals included 7 cats and 12 dogs. Despite the fact that these animals had received from seven to ten times as many reinforcements as the controls, none of them showed the slightest evidence of learning. Often they even seemed more tractable than before the experiment! That failure to respond at this time was not due to the condition of the animals was proven by control tests carried out on five cats and six dogs, in which they were conditioned immediately after the tests for learning under curare. All of these animals learned in one or two trials.

To demonstrate that learning is possible under curare, the observations of Experiment 2 on the pupillary reflex were carried out on part of the original group of animals.

Experiment 2.—The electric shock which was given in experiment 1 as an unconditioned stimulus is also an unconditioned stimulus for pupillary dilatation, a response which is

not affected by ordinary doses of curare. This response is so strong that, despite a light shining in the animal's eyes, the pupil often dilated to its fullest extent.

The order of application of stimuli was light, bell, shock. At the beginning of the experiment the pupil contracted to the light, made no change to the bell and dilated to pain. After several repetitions of this stimulation, the dilatation of the pupil appeared to the bell before the application of the shock. Of six cats, the phenomenon was unquestionable in four, dubious in one, and not found in one. It was clear in five of seven dogs.

The speed of acquisition of this conditioned reflex was very rapid, two to six repetitions sufficing in the animals observed.

It thus appears certain that cortical activity (to the extent required for the acquisition of the conditioned pupillary response) is not depressed by curare, at least in the amounts used in this experiment.

Experiment 3.—It was thought that, although the animal could not learn to leap from the grill while under curare, it might be possible to extinguish this learned response. Three cats were conditioned without curare, then given the drug. When paralyzed the animals were placed in the grill and given the usual training series, except that the shock was not given. The buzzer sounded as usual, but the coil was disconnected from the grill.

One of the animals died before tests for retention were made. When the other animals had recovered from the effects of curare, the series of tests for response to the various conditioned stimuli was repeated. Each of the cats tested showed practically no change from its previous behavior, the strength of the responses occurring in the six different situations being no greater, and no less.

In the case of one of these animals, the same experiment was repeated a week later, with the same results.

Experiment 4.—Concurrently with Experiment 3, the conditioned pupillary response to the bell was extinguished by the unreinforced stimulations. The effects were noticeable after about 100 repetitions, but about 150 were required to extin-

guish completely. There are several points of interest in this experiment. In the first place, we find that this smooth muscle response (dilatation of the pupil) is extinguished, while the remainder of the total pattern of response is unaffected. This appears to differ somewhat from the individuation of components of the response as reported by Beritoff (1), Watson (18), and others, for in this case the pupillary response is totally extinguished, while the skeletal components remain at full strength.

In the second place, it should be noted that *this* pupillary response is extinguished only after a comparatively enormous number of trials, as compared with the pupillary response in human beings as studied by Cason (2). We suggest one of two alternative hypotheses: either the smooth-muscle emotional [4] response, like the skeletal emotional responses, contradicts the accepted Pavlovian principle of experimental extinction; or normally the more dominant skeletal muscle components inhibit out the pupillary reaction.

Experiment 5.—In this experiment an animal (cat) was conditioned specifically to the buzzer-grill situation without curare. It was negative to the grill alone and to the grill-light-bell set.

The purpose of the experiment was to attempt to attach a new stimulus onto a previously conditioned response. It was thought reasonable to assume that this might occur, since theoretically motor responses (and their resultant proprioceptive impulses) play no essential part in associations between primary sensory projection areas of the cerebrum.

When the animal was tested after the experiment, the response to light and bell were still negative, and to the buzzer-grill situation still positive. It appears from this that not even associations between stimuli for skeletal muscle responses can occur under curare.

Experiment 6.—Our previous experiments seem to prove that adaptive responses are not learned under curare. The possibility still remained that 'latent learning' may have occurred. It is possible, for example, that the simultaneous

[4] Emotional, because the unconditioned stimulus is pain. This viewpoint is elaborated elsewhere (6).

presentation of stimuli under curare may bring about brain changes which still cannot be organized into a 'total reaction pattern' without the occurrence of a response.

An experiment was planned to test this hypothesis, using a litter of four young dogs. Two experimental animals were given an initial training period under curare as described in Experiment 1. All four animals were then conditioned under normal circumstances.

One of the two control animals learned in two trials, the other in one. Of the two experimental animals, one learned in a single repetition, and the other did not learn *to jump out of the grid* until the fifth trial. After the first repetition, however, he showed unmistakable fear responses to the grill and especially to the bell, and finally learned the jumping-out response when *outside the grill*, between the fourth and fifth trials.

The four animals were tested for retention one, two, three, and seven days after the training. No differences could be found between control and experimental animals in either speed or violence of the response. Little forgetting, however, was found in any of the animals over this period of time.

Experiment 7.—We next attempted to study the effect of limited striped muscle activity during the training series. The follow-procedure was used: on the day preceding training, the femoral artery and vein of one leg were exposed under anesthesia. Before the injection of curare, the femoral artery was closed by a bull-dog clamp and curare injected into the vein. The regular training series was then given, the clamp removed and physostigmine injected. After recovery the animal was tested in the usual way.

Technical difficulties have so far prevented us from obtaining clear-cut results on this experiment. Only one case has recovered in which the ligation appeared to be successful, and this animal appeared to show marked uneasiness to the conditioning stimuli although the adaptive reaction of escaping from the grill did not appear.

Theoretically it should be possible by increasing the amount of curare-free muscle tissue to find some minimal point at which learning occurs.

Experiment 8.—Although the animals fail to learn the adaptive reaction of jumping from the grill, a response which might be assumed to represent an integration between concatenated reflex activities, it was still thought possible that a simple reflex such as flexion of the leg to pain might be conditioned. To test this hypothesis, the second apparatus described was employed.

The animal was placed in the stocks, with one forepaw in a position to receive faradic shocks. The usual training series was then given. Under curare, no learning occurred.

Possible Extensions of the Technique

Many extensions of the curare technique for the investigation of the learning process may be suggested. Chief among these are (1) the effect of passive movement and resultant proprioceptive stimulation upon the learning process; (2) the possibility of rebuilding a previously forgotten or extinguished response under curare; (3) the effect of curarization upon the retention and formation of delayed responses; (4) the introspective report of human subjects (granting that the technical difficulties were removed sufficiently to make this permissible).

No successful attempt has so far been made to purify the drug curare, with the result that certain serious difficulties interfere with successful experimentation. Chief among these is the effect of curine, a poisonous alkaloid associated with the active principle of curare, in depressing the heart.

Wenner and Blanchard (**19**) have demonstrated changes in blood constitution under curare which, however, should not be severe enough seriously to affect the central nervous system. These results have been confirmed and extended in the course of our own investigations (**7**).

Our observations indicate that a marked fall in blood pressure may occur. This, we believe, may occasionally be severe enough to influence the central nervous system, and may account for the failure of pupillary conditioning in some animals. Such an hypothesis is supported by the observation that unusually large injections of curare may be associated with abolition of all pupillary responses, even though the animal may subsequently recover.

The technique of artificial respiration by tracheal insufflation is in no sense ideal, as it represents a source of extraneous nociceptive stimulation, and is a less reliable source of respiration than would be afforded by the Drinker Respirator. Our control experiments, however, show that the objections, while serious, do not prejudice the results obtained.

Implications

Briefly, we believe that the implications of this experiment, as they apply to various related fields, are as follows:

(1) Educational psychology. The importance of pupil activity in the learning process is emphasized, since it appears that presentation of stimuli alone will not cause learning if no reaction is made.

(2) Physiological psychology. The view of Watson, Dunlap, Dashiell, Washburn and Langfeld that thinking involves peripheral as well as central activity and may be roughly described as 'implicit speech' is substantiated.

(3) Speech pathology. Our results support Dejerine's concept of the loss of 'verbal images' as an important factor in aphasia, and contradict strongly the position of Marie and of Head that true aphasia does not involve loss of motor responses.

(4) Physiology. Conditioned reflexes are only possible if a response is made, and do not result merely from stimuli presented simultaneously.

(5) Pharmacology. Curare does not paralyze the central nervous system.

Summary

1. Complete skeletal muscle paralysis in the intact animal may be obtained by the use of curare.

2. Under this condition animals fail to learn a simple adaptive reaction in thirty repetitions, although control animals learn in less than three.

3. Conditioned pupillary dilatation may be developed under curare.

4. Experimental extinction of the adaptive reaction is not possible under curare, although the pupillary extinction is possible.

5. Latent learning under curare paralysis has not been demonstrated.

6. Association of new stimuli to previously conditioned responses has not been obtained.

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References

1. Beritoff, J., Ueber die individuell erworbene Tatigkeit des Zentralnervensystems bei Tauben, *Pflug. Arch. f. ges. Physiol.*, 1926, **213**, 370–406.
2. Cason, H., The conditioned pupillary reaction, *J. Exper. Psychol.*, 1922, **5**, 108–46.
3. Clark, Ruth S., An experimental study of silent thinking. *Arch. Psychol.*, 1922. No. 48.
4. Dana, C. L., Anatomic seat of the emotions, *Arch. Neur. and Psychiat.*, 1921, **6**, 634–39.
5. Gates, A. I., Recitation as a factor in memorizing. *Sch. and Soc.*, 1917, **6**, 743–749.
6. Harlow, H. F., and Stagner, R., Psychology of feelings and emotions. II. Theory of emotions. *Psychol. Rev.*, 1933 (March).
7. Harlow, H. F., Stagner, R., and Cohen, P., Changes in blood constitution under curare paralysis (unpublished study).
8. Head, H., Studies in neurology (2 vols.). London, 1920.
9. Jacobson, E., Electrical measurements of neuromuscular states during mental activities. II. Imagination and recollection of various muscular acts, *Amer. J. Physiol.*, 1930, **94**, 22–34.
10. Jacobson, E., Electrical measurements of neuromuscular states during mental activities. VI. A note on mental activities concerning an amputated limb, *Amer. J. Physiol.*, 1931, **96**, 122–125.
11. Jacobson, E., Electrical measurements of neuromuscular states during mental activities. VII. Imagination, recollection and abstract thinking involving the speech musculature, *Amer. J. Physiol.*, 1931, **97**, 200–209.
12. James, Wm., Principles of psychology (2 vols.). New York, 1904.
13. Lashley, K. S., Studies of cerebral function in learning. V. Retention of motor habits after the destruction of the so-called motor areas in primates, *Arch. Neur. and Psychiat.*, 1924, **12**, 249–276.
14. Lashley, K. S., and Ball, Josephine, Spinal conduction and kinesthetic sensitivity in the maze habit, *J. Comp. Psychol.*, 1929, **9**, 70–106.
15. Lashley, K. S., and McCarthy, Dorothea A., Survival of maze habit after cerebellar injuries, *J. Comp. Psychol.*, 1926, **6**, 423–33.
16. Sollman, T., Manual of Pharmacology. Philadelphia, 1932.
17. Thorson, Agnes M., Relation of tongue movements to internal speech, *J. Exper. Psychol.*, 1925, **8**, 1–33.
18. Watson, J. B., Psychology from the standpoint of a behaviorist. Philadelphia, 1924.
19. Wenner, W. F., and Blanchard, E. W., Effect of intravenous injection of alkali on action of curare, *Amer. J. Physiol.*, 1930, **91**, 563–66.

ASSOCIATIONS BETWEEN THE FAMILIAR AND THE UNFAMILIAR

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The purpose of the present study was to throw further light on the processes involved in learning paired associates when the items in the pairs were the most familiar words and the most unfamiliar syllables that could be obtained. The learning situation was similar to that which is present in learning foreign language vocabularies. We obtained measures of the relative efficiency of learning and retaining 4 kinds of pairs, when the pairs were made up of a familiar word and a familiar word, an unfamiliar syllable and a familiar word, a familiar word and an unfamiliar syllable, and an unfamiliar syllable and an unfamiliar syllable. The pairs were presented to the *S* both visually and orally under controlled but fairly natural conditions. Data were also secured on the relative efficiency of spaced and unspaced learning, and on the influence of position in the series.[1]

Only two previous investigations seem to have been made of the present subject. Roback and Groetzinger [2] studied the relative efficiency with which pairs of familiar and unfamiliar proper names could be connected with each other. Three psychologically trained *S*'s read the names aloud as they were presented to them by an exposure apparatus. The results were irregular and inconclusive. Winzen [3] made a study of associating words and nonsense syllables under a variety of conditions, and the syllables used were the same as those which

[1] For some assistance in the later stages of preparing the material and in conducting the experiment with 1/3 of the *S*'s in Part I, I am under obligation to Mr. A. H. Maslow.

[2] A. A. Roback and M. Groetzinger, The applied psychology of names, *J. Appl. Psychol.*, 1920, **4**, 348–360.

[3] Karl Winzen, Die Abhängigkeit der paarweisen Assoziation von der Stellung des besser haftenden Gliedes, *Zsch. f. Psychol.*, 1921, **86**, 236–252.

had been previously used by Müller and Pilzecker.[4] Winzen experimented with forward and backward association, with familiar words and syllables made familiar by use, and with stronger accent, double reading, and higher visual attention value. He attempted to make the learning as mechanical as possible and to avoid memory aids and meaningful associations. His results seemed to favor the conclusion that 2 activities can be associated with each other more efficiently when the more familiar activity is in the first place than when the less familiar activity is in the first place.

Part I. Associations Between *F–F*, *U–F*, *F–U*, and *U–U* Pairs

Subjects.—Most of the *S*'s were university students, and their age and sex distribution for the two modes of presentation was as follows:

Age	Visual		Auditory	
	M.	F.	M.	F.
35–39	1		1	
30–34		1	1	1
25–29	3	3	1	4
20–24	5	7	6	8
15–19		6	2	4
Totals	9	17	11	17
	26		28	
	54			

Material.—The *F* words and *U* syllables were the same as those used by the writer in a previous study. [Lists of these words and syllables are given in Tables II and III, in Specific serial learning; a study of backward association, *J. Exper. Psychol.*, 1926, **9**, 195–227.] The words were among the most familiar in the English language, and the syllables were the most unfamiliar 3-letter combinations that could be found. Examples of the *F* words that were used are: all, bed, cow, dog, fat, let, and rag; and examples of the *U* syllables are: bav, dax, fev, gex, heg, kig, miv, nuv, rux, taz, vub, wug, and zeg. All of the words and syllables were of 3 letters, and they had the special advantage that all of them could be clearly pronounced.

Each of 18 lists, of 16 pairs each, was typewritten on a separate sheet of paper. In each list there were 4 *F–F* pairs, 4 *U–F* pairs, 4 *F–U* pairs, and 4 *U–U* pairs; and the 4 kinds of pairs were rotated to equalize position.

Procedure.—The *S*'s were taken individually, and the writer was the experimenter in 2/3 of the cases.

[4] G. E. Müller and A. Pilzecker, Experimentelle Beiträge zur Lehre vom Gedächtnis, *Zsch. f. Psychol., Ergänzungsband* I, 1900, 194.

1. *S* studied one list at a time, and was instructed to study each pair in such a way that later when the first item was spoken by the *E* he could or would try to give the second item. He was urged to distribute his practice and effort equally between all of the different pairs. *E* assured *S* that the first item in each pair would always be the stimulus-item.

2. *S* was asked to use any method he desired in trying to connect the items. The method actually employed by different *S*'s varied considerably, but each *S* tended to continue using the method that seemed most natural to him and which he thought was most efficient.

3. *S* was instructed to study each pair as a separate unit, and was asked not to try to learn the pairs in any order, since the pairs would always be taken in an irregular order in the later tests for Learning and Retention.

4. The time allowed for studying the successive lists of pairs was varied in such a way that *S* generally learned 1, 2, or 3 pairs of each kind out of a possible 4. The time for a list ranged from $2\frac{2}{3}$ to $10\frac{2}{3}$ min, and it was generally between 4 and 8 min. Varying the time adapted the experiment to the unequal learning abilities of the different *S*'s; but this procedure did not prejudice the results in favor of any one of the 4 kinds of pairs.

5. At the end of the time allowed for studying a list, *E* tested *S*'s Learning, and the pairs were taken in an irregular order. *E* pronounced and then spelled each stimulus-item, as 'rag—r-a-g' or 'dax—d-a-x.' *S* was allowed as much time as he desired in trying to recall the response-item, and he said 'No' when he was fairly certain that he could not recall it. When the response was correct, *E* recorded a score of 1 for the pair, and gave the next stimulus-item without unnecessary delay. If all of the letters in the response were wrong, *E* said 'No.' If the response was partly correct, *E* told *S* which letters were right and gave him one further opportunity of recalling the whole word or syllable. No credit was allowed if the response was not finally entirely correct.

6. At some time during the following day, *S*'s Retention of the paired items was tested in a similar manner, but without further practice, and the pairs were again taken in an irregular order.

7. An attempt was made to use each of the 18 lists the same number of times, and the total number of lists used with 1 *S* was generally 4, 5, or 6.

8. The first experimental period lasted between 1 and $1\frac{1}{2}$ hrs, and the test for Retention on the second day required from 15 to 25 min.

The procedure described above was followed for all *S*'s, but the presentation of the material was Visual for some *S*'s and Auditory for others.

In the Visual presentation, a list was handed to *S*, and he studied the paired items in his own way. He was instructed to distribute his time and effort equally between the different pairs.

In the Auditory presentation, *E* read the paired items aloud to *S*, at regular intervals. The 2 items in each pair were spelled out, as 'g-e-x—t-a-z,' or 'w-u-g—a-l-l.' *S* was asked to be listening for the next pair which would be given without warning, so that he would not ask *E* to repeat, and he was instructed to attempt to connect the 2 items only during the time interval intended for that pair.

In the Auditory presentation, each list was read to *S* 1 or 2 times, and the procedure that was followed made a comparison possible between the relative efficiency of Spaced and Unspaced Learning. One list was read once with 20 sec for each pair, and the following list was read twice with 10 sec for each pair; or 1 list was read twice with 15 sec for each pair, and the following list was read once with 30 sec for each pair.

The procedure was alternated in this way, and the total time spent on 2 adjacen lists was the same, and the only difference in the external conditions was in the spaced and unspaced periods of study and effort.

Results.—The results of Part I are summarized in Tables 1, 2, and 3. Scores are given for Visual and Auditory presentation, and for Learning and Retention. In the case of each S,

TABLE 1

RELATIVE RANKS OF *F–F*, *U–F*, *F–U* AND *U–U* FOR DIFFERENT SUBJECTS IN LEARNING AND RETAINING THE PAIRS OF WORDS AND SYLLABLES

Rank			1	1½	2	2½	3	3½	4	Mean Rank	Rank Order
Visual Presentation $N = 26$	Learning	*F–F*	22	1	2		1			1.17	1
		U–F	1		10	4	7	2	2	2.58	2
		F–U	2	1	5	4	10	2	2	2.63	3
		U–U	1		1	2	2	2	18	3.58	4
	Retention After One Day	*F–F*	25	1						1.02	1
		U–F		1	13	3	5	2	2	2.50	2
		F–U			3	4	9	3	7	3.13	3
		U–U			3	1	8	3	11	3.35	4
Auditory Presentation $N = 28$	Learning	*F–F*	26	1	1					1.05	1
		U–F		1	3	3	16	3	2	2.91	3
		F–U	1		18	3	2	1	3	2.36	2
		U–U			1		5	4	18	3.68	4
	Retention After One Day	*F–F*	26	1	1					1.05	1
		U–F	1	1	11	5	8	1	1	2.45	2
		F–U			7	4	14	1	2	2.77	3
		U–U			1	3	1		23	3.73	4

TABLE 2

RELATIVE EFFICIENCY OF LEARNING AND RETAINING *F–F*, *U–F* *F–U*, AND *U–U* PAIRS OF WORDS AND SYLLABLES: COMBINED RESULTS

Pairs of Words			*F-F*	*U-F*	*F-U*	*U-U*
Visual Presentation	Learning	N.	134	134	134	134
		Av.	3.28±.05	2.32±.07	2.38±.07	1.81±.07
		S.D.	.86	1.12	1.13	1.26
	Retention After One Day	N.	134	134	134	134
		Av.	1.99±.07	1.00±.06	.76±.05	.54±.05
		S.D.	1.21	1.04	.87	.80
Auditory Presentation	Learning	N.	133	133	133	133
		Av.	3.35±.05	1.89±.07	2.23±.06	1.33±.07
		S.D.	.82	1.14	1.10	1.16
	Retention After One Day	N.	133	133	133	133
		Av.	2.26±.07	1.22±.06	1.21±.06	.57±.05
		S.D.	1.14	1.09	1.10	.87

an average score was calculated for each of the 4 kinds of pairs in all 4 situations, and Table 1 shows the relative ranks of the 4 kinds of pairs. In Visual presentation, 22 *S*'s out of 26 learned the *F–F* pairs more efficiently than the 3 other kinds of pairs (a rank of 1). The score of 1 *S* for *F–F* was a tie between first and second places (a rank of $1\frac{1}{2}$). The Mean Rank for Learning *F–F* was 1.17. Each of the 4 kinds of pairs has 4 Mean Rank scores, and when these mean scores for each pair are averaged, the following Average Ranks are obtained:

Pair	Av. Rank
F–F	1.07
U–F	2.61
F–U	2.72
U–U	3.58

Table 2 shows the combined results of all of the *S*'s on the relative efficiency of Learning and Retaining the 4 kinds of pairs. In each list of paired items there was a score of 0, 1, 2, 3, or 4 for each of the 4 kinds of pairs. The number of lists used was not the same for all *S*'s; and *N* in the table indicates the total number of lists used by all of the *S*'s. The *N. Av.*, *S.D.*, and $P.E._{Av.}$ are given for each of the 16 distributions. The *F–F* pairs were first and the *U–U* pairs were last on all 4 tests. In Visual presentation, *U–F* and *F–U* were equal in Learning, but *U–F* was superior in Retention. In Auditory presentation, *U–F* was below *F–U* in Learning, but they were equal in Retention. If the average scores for Learning are taken as a base of 100, the percents which the average Retention scores are of the average Learning scores are as follows:

		F-F	*U-F*	*F-U*	*U-U*
Visual	*Learning*	100	100	100	100
	Retention	61	43	32	30
Auditory	*Learning*	100	100	100	100
	Retention	67	65	54	43

If the average scores for *F–F* are taken as a base of 100, the percents which the average *U–F*, *F–U*, and *U–U* scores are of the average *F–F* scores are as follows:

		F-F	U-F	F-U	U-U
Visual	*Learning*	100	71	73	55
	Retention	100	50	38	27
Auditory	*Learning*	100	56	67	40
	Retention	100	54	54	25

These results give reliable measures of the relative efficiency of Learning and Retaining *F–F* and *U–U* pairs, but they apparently do not afford an adequate basis for a general conclusion on the relative efficiency of Learning and Retaining the *U–F* and *F–U* pairs, principally on account of the irregularities in the results for Learning as compared with those for Retention. For this reason, a further study of the *U–F* and *F–U* pairs is made in Part II.

TABLE 3

RELATIVE EFFICIENCY OF SPACED AND UNSPACED LEARNING, WITH AUDITORY PRESENTATION: COMBINED RESULTS

Kind of Learning			Spaced	Unspaced
Learning	*F–F*	N.	64	64
		Av.	3.48±.06	3.23±.07
		S.D.	.75	.86
	U–F	N.	64	64
		Av.	2.20±.09	1.58±.09
		S.D.	1.08	1.10
	F–U	N.	64	64
		Av.	2.28±.09	2.14±.09
		S.D.	1.04	1.10
	U–U	N.	64	64
		Av.	1.53±.09	1.13±.10
		S.D.	1.09	1.22
Retention After One Day	*F–F*	N.	64	64
		Av.	2.34±.08	2.19±.11
		S.D.	1.00	1.27
	U–F	N.	64	64
		Av.	1.36±.09	1.09±.09
		S.D.	1.11	1.06
	F–U	N.	64	64
		Av.	1.22±.09	1.14±.09
		S.D.	1.04	1.06
	U–U	N.	64	64
		Av.	.67±.07	.50±.07
		S.D.	.87	.88

Table 3 shows the relative scores for Spaced and Unspaced Learning, with Auditory presentation. One hundred and twenty-eight of the lists were paired with each other in such a way that in the case of 64 pairs of lists a good comparison could be made with the same *S* in Spaced and Unspaced Learning. In the procedure that was followed, *E*, for example, read a list twice and allowed *S* 15 sec for each pair (Spaced Learning), and *E* then read the following list once and allowed *S* 30 sec for each pair (Unspaced Learning). The total time spent in trying to learn the pairs was the same in Spaced and Unspaced Learning. The results in the table show that Spaced Learning is more efficient than Unspaced for each kind of pair in the tests for both Learning and Retention. Although some of the differences in the table are not reliable, the reliability of the general conclusion in favor of the Spaced Learning of this kind of material is greatly increased because the same result was obtained in 8 different comparisons.

Part II. Associations Between *U–F* and *F–U* Pairs

In the second experiment a further study was made of the relative efficiency of Learning and Retaining *U–F* and *F–U* pairs, and the most *F* of the *F* words and the most *U* of the *U* syllables were used as learning material. *U–F* pairs for certain *S*'s were reversed and used in exactly the same way as *F–U* pairs for an equal number of other *S*'s. The *F–U* pairs were also reversed and used in the same way, so that the only difference between the *U–F* and *F–U* pairs was in the order of the 2 items in the pairs.

Material.—The 288 words and 288 syllables used in Part I were selected by chance from lists of 300 words and 300 syllables which had been used in a previous study. In preparing the material for the present experiment, the same 300 words and 300 syllables were submitted to 24 judges (16 undergraduate and 6 graduate students, and 15 men and 9 women). Each judge was asked to select at least 25 of the *F* words that seemed the least *F* to him, and at least 25 of the *U* syllables that seemed the least *U* to him. On the basis of these combined judgments, 52 of the least *F* words and 52 of the

least *U* syllables were excluded, and the remaining 248 most *F* words and 248 most *U* syllables were used as learning material. These words and syllables, which are given in Tables 4 and 5, seem to constitute excellent learning material.

TABLE 4

248 Familiar Words

ACT	ADD	AGE	AID	AIM	AIR	ALL	AND	ANT	APE	ARE	ARM	ART
ASH	ASK	ATE	BAD	BAG	BAR	BAT	BAY	BED	BEE	BEG	BET	BID
BIT	BOY	BUD	BUG	BUN	BUS	BUT	BUY	CAB	CAN	CAP	CAR	CAT
COT	COW	CRY	CUP	DAY	DEN	DEW	DID	DIE	DIG	DIM	DIN	DIP
DOG	DOT	DRY	DUE	DUG	EAR	EAT	EGG	ELM	END	EVE	EYE	FAN
FAR	FAT	FED	FEE	FIG	FIT	FIX	FLY	FOE	FOG	FOR	FOX	FRY
FUN	GAS	GAY	GEM	GET	GOT	GUM	GUN	HAD	HAM	HAS	HAT	HAY
HEN	HER	HID	HIP	HIS	HIT	HOG	HOP	HOT	HOW	HUG	HUM	HUT
ICE	ILL	INK	INN	ITS	JAM	JAR	JAW	JOB	JOY	JUG	KEY	KID
LAD	LAG	LAP	LAY	LED	LEG	LET	LID	LIE	LIP	LIT	LOG	LOT
LOW	MAN	MAP	MAT	MAY	MEN	MIX	MUD	MUG	NAP	NET	NEW	NOD
NOR	NOT	NOW	NUN	NUT	OAK	OAT	ODD	OFF	OIL	OLD	ONE	OUR
OUT	OWE	OWL	OWN	PAD	PAN	PAT	PAW	PAY	PEG	PEN	PET	PIE
PIG	PIN	PIT	POP	POT	PUP	PUT	RAG	RAP	RAT	RAW	RAY	RED
RIB	RID	RIM	RIP	ROB	ROD	ROT	ROW	RUB	RUG	RUN	SAD	SAP
SAT	SAW	SAY	SEA	SET	SEW	SHE	SHY	SIN	SIP	SIR	SIT	SIX
SKY	SLY	SOB	SON	SPY	SUM	SUN	TAG	TAN	TAP	TAR	TAX	TEA
TEN	THE	TIE	TIN	TIP	TOE	TON	TOO	TOP	TOY	TRY	TUB	TUG
TWO	USE	VOW	WAR	WAS	WED	WET	WHO	WHY	WIN	WIT	YES	YET
YOU												

TABLE 5

248 Unfamiliar Syllables

BAF	BAP	BAV	BAZ	BEM	BEP	BEX	BIV	BOF	BOP	BOV	BUP	BUV
DAP	DAV	DAX	DEG	DEV	DEZ	DIB	DOB	DOY	DUR	DUS	DUT	DUV
FAP	FAV	FEG	FEK	FEP	FEV	FEX	FID	FIK	FIM	FIP	FOD	FOS
FOV	FUB	FUP	FUV	GAX	GEB	GED	GEK	GEP	GEV	GEX	GEZ	GID
GIK	GIR	GIS	GIX	GOK	GOS	GOX	GUB	GUK	GUP	GUR	GUX	HEB
HEF	HEG	HES	HEX	HIB	HIF	HIG	HUD	HUK	HUV	HUX	HUZ	KAX
KAZ	KEB	KEF	KEM	KES	KEV	KEX	KIB	KIF	KIG	KIV	KUV	KUX
LEB	LEZ	LIG	LIS	LOY	LOZ	MAF	MAV	MEF	MEP	MEV	MEZ	MIB
MIG	MIP	MIV	MOF	MOV	MUB	MUP	MUX	NAD	NAF	NAR	NAZ	NEF
NEG	NEP	NIV	NIZ	NOF	NOY	NUG	NUK	NUP	NUV	PAB	PAF	PEB
PEF	PEM	PIB	PIV	POB	POF	POG	POV	POY	POZ	PUV	PUZ	RET
REZ	RIK	RIV	ROF	RUK	RUP	RUV	RUX	SEB	SEG	SOF	SOV	SOZ
SUF	SUG	SUL	SUV	TAV	TAZ	TEB	TEF	TEG	TEP	TEV	TEY	TIB
TIV	TOF	TOV	TOZ	TUD	TUP	TUS	TUV	VAB	VAD	VAF	VAM	VAP
VAW	VEB	VED	VEF	VEP	VIB	VID	VIG	VIP	VOB	VOD	VOF	VOK
VOP	VOZ	VUB	VUD	VUF	VUG	VUM	VUP	VUR	VUT	VUX	VUZ	WAB
WEF	WEM	WEZ	WIB	WIX	WOB	WOG	WOX	WUB	WUG	WUK	WUP	WUV
WUX	ZAB	ZAK	ZAN	ZAR	ZAX	ZEF	ZEG	ZEM	ZEN	ZER	ZID	ZIF
ZIL	ZIV	ZOF	ZOM	ZOR	ZOV	ZOY	ZUB	ZUD	ZUF	ZUG	ZUL	ZUT
ZUV												

With these *F* words and *U* syllables, 31 lists, of *U–F* and *F–U* pairs, were constructed; and in each list there were 8 pairs, 4 *U–F* and 4 *F–U* pairs. An attempt was made to avoid the obviously easy pairs. The above lists were numbered

consecutively from 1 to 31, and they will be referred to as the *A*-Lists. A second set of material, the *B*-Lists, was prepared by reversing the 2 items in each of the 248 pairs of the *A*-Lists, each pair remaining in the same position in the list. In constructing the *B*-Lists the *U–F* pairs of the *A*-Lists were changed to *F–U* pairs, and the *F–U* pairs of the *A*-Lists were changed to *U–F* pairs. The *B*-Lists were also numbered consecutively from 1 to 31. In the procedure that was followed, each of the *A*-Lists was used the same number of times as the corresponding *B*-List, that is, *A*1 was used the same number of times as *B*1, and *A*4 the same number of times as *B*4. The *A*-Lists and the *B*-Lists had to be used with different *S*'s.

Subjects.—Most of the *S*'s were university students, and their age and sex distribution for the 2 modes of presentation was as follows:

Age	Visual		Auditory	
	M.	F.	M.	F.
30–34	2	1		
25–29				
20–24	1	12	5	7
15–19		3	4	12
Totals	3	16	9	19
	19		28	
	47			

Procedure.—In addition to the differences in the material and in the construction of the lists described above, the present procedure differed from that used in the first experiment only in the following respects:

1. The writer was the experimenter in all cases.

2. The total time allowed for a list was generally between 2 and 4 min.

3. The *A*-Lists and the corresponding *B*-Lists were used the same number of times but with different *S*'s in the Visual presentation and also in the Auditory presentation.

Results.—The results of Part II are summarized in Tables 6, 7, and 8. Table 6 shows the relative ranks of *U–F* and

TABLE 6

RELATIVE RANKS OF *U–F* AND *F–U* FOR DIFFERENT SUBJECTS IN LEARNING AND RETAINING THE PAIRS OF WORDS AND SYLLABLES

Rank			1	1½	2	Mean Rank	Rank Order
Visual Presentation $N = 19$	Learning	*U–F*	6	1	12	1.66	2
		F–U	12	1	6	1.34	1
	Retention After One Day	*U–F*	11	2	6	1.37	1
		F–U	6	2	11	1.63	2
Auditory Presentation $N = 28$	Learning	*U–F*	9	2	17	1.64	2
		F–U	17	2	9	1.36	1
	Retention After One Day	*U–F*	11	1	16	1.59	2
		F–U	16	1	11	1.41	1

F–U pairs for different *S*'s. The *F–U* pairs are above the *U–F* on all tests except Retention with Visual presentation. If the Mean Rank scores are combined, the following Average Ranks are obtained:

Pair	Av. Rank
U–F	1.56
F–U	1.43

Table 7 shows the combined results of all *S*'s on the efficiency of Learning and Retaining the *U–F* and *F–U* pairs. In each list of paired items there was a score of 0, 1, 2, 3, or 4 for each kind of pair. In Visual presentation, *F–U* was slightly above *U–F* in Learning, but the 2 were almost equal in Retention. In Auditory presentation, *F–U* was above *U–F* in both Learning and Retention. Since the distribution of study and effort could be more completely controlled in the procedure with Auditory presentation, it seems quite probable that 2 items in paired associates learning can be learned and retained more efficiently when the more familiar of the 2 items is in the first place.

In the procedure with Visual presentation, a card on which the 8 pairs were typewritten was handed to the *S*, and he was asked to distribute his time and effort equally between the different pairs. Table 8 shows the percent of items that were correct in each of the 8 positions. Position in a series of paired associates does not seem to have any influence except in the

TABLE 7

RELATIVE EFFICIENCY OF LEARNING AND RETAINING *U–F* AND *F–U* PAIRS OF WORDS AND SYLLABLES: COMBINED RESULTS

Pairs of Words			*U-F*	*F-U*
Visual Presentation	Learning	N.	248	248
		Av.	2.83±.04	2.92±.04
		S.D.	1.05	1.05
	Retention After One Day	N.	248	248
		Av.	.50±.03	.46±.03
		S.D.	.72	.68
Auditory Presentation	Learning	N.	248	248
		Av.	2.60±.05	2.75±.04
		S.D.	1.09	1.05
	Retention After One Day	N.	248	248
		Av.	.75±.04	.88±.04
		S.D.	.88	.85

case of the last items in the list, where a slightly smaller percent of pairs are learned and retained.

TABLE 8

PERCENT OF ITEMS CORRECT IN EACH OF THE EIGHT POSITIONS IN VISUAL PRESENTATION

Position	1	2	3	4	5	6	7	8
Learning	73	74	75	72	75	73	69	65
Retention After One Day	13	11	13	15	12	11	12	9

The conclusion in regard to the slight superiority of learning and retaining *F–U* pairs as compared with *U–F* pairs is in harmony with the results obtained by Winzen. It might have been thought that the *U–F* pairs would be superior, because in the tests for learning and retention *E* gave the *U* item and *S* was asked to recall the *F* item. *S* already knew how to spell the *F* item and was entirely familiar with it before the experiment began, and one might have expected that it would be easier for *S* to give an *F* item than a *U* item. However, the *F* item may have been a more adequate stimulus, and may have evoked a larger number of natural associations when *S* was trying to recall, thereby improving the relative scores for learning and retaining the *F–U* pairs.

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A TECHNIQUE FOR THE TAKING OF LONG OSCILLOGRAPH RECORDS

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The oscillograph has long been a useful instrument in the analysis of electric currents of all sorts. Of late, its usefulness as an instrument of sound-analysis has begun to be appreciated, particularly in cases where fine differences in timbre are important determinants of the tone-quality. For this purpose, the sound of the voice, violin, or other instrument to be studied, is picked up by a microphone similar to those used in broadcasting. In other words, the pulsations of the air known as 'sound-waves' affect this microphone in such a way as to be transformed into minute pulsations of an electric current exactly duplicating and synchronizing with the pulsations of the air-wave. These electric pulsations are then amplified with the aid of vacuum-tubes, and brought to an oscillograph.

Many commercial oscillographs, however, cannot realize their full value because they are not equipped with auxiliary apparatus to make possible the photography of tones lasting about a second or more, *with the waves sufficiently spread out* for purposes of analysis. This last is a very important consideration in the field of music, for it appears that important differences in tone-quality are frequently to be found in the high and very high partials. Indeed, as an instance, a study of vocal quality which has been under way at the Peabody for the past two years, has shown that the frequencies in the neighborhood of 3000 dv are of considerable importance in determining the artistic value of voice-quality.

If such high frequencies are to be separated sufficiently for satisfactory reading, the film-speed should be at least 10 feet a second. Also, it is frequently desirable to have records of a tone lasting as long as a second, in order to analyze the vibrato, that important ingredient of 'tone-quality.'[1] Thus

[1] Cheslock, L., Introductory Study on Violin Vibrato, Peabody Institute Research Studies in Music, No. 1.

we see the necessity of taking rapid oscillograph records of at least 10 feet in length. Very few oscillographs are equipped to handle records this long, at such a high film-speed. As a result, it became necessary for us to devise a method of recording that would make them possible, and since the oscillograph is coming more and more into general use, it is thought that a description of our apparatus would be of value to other investigators.

Various methods were considered. The ideal way, of course, would be to have a drum with a large enough circumference to take as long a film as we wished. But this was rejected because of the difficulty in procuring such a drum, or in mounting it accurately enough to avoid vibration when driven at the necessary speed. The next best way would be to have a smaller drum and in conjunction with it some means of shifting it laterally in front of the light-slit of the oscillograph, in order to secure a helical record of say 6 or 7 revolutions on the one drum. Helical-shift kymographs operate on this principle, but are too small in diameter. A larger drum is necessary, with its entire width covered with film. There is an excellent device of this type in use at the Bureau of Standards in Washington, consisting of a heavy drum about three feet in diameter, which engages in a screw thread so as to shift it laterally while making the record, thus tracing a long helical oscillogram. The cost of this was prohibitive, however.

We next considered the possibility of placing a slowly increasing electrical bias on the oscillograph vibrator, so as to cause the point-of-light to trace a helical line, but this introduced among other problems the difficulty of maintaining constant contact by using a sliding brush. If contact is not maintained perfect, inductive kicks will be introduced. So we gave up the helical idea. (There is of course a very slight displacement error in all helical records in that the amplitude is not strictly perpendicular to the zero-line.) We also considered a machine on the principle of the cancellation machines used in Post Offices, to shoot a series of cut films across the light slit, but gave this up because of our desire for constant and known film speed.

There seemed to us to be but one other method, the use of a long, endless belt with two small drums, and preliminary experiments showed this method to be feasible.

After some attempts with a woven white cotton belt, which failed because of its weight, stiffness, and a thick splice, we tried ordinary table oil-cloth, of black color, with the ends glued together. This was about $14\frac{1}{2}$ feet long, and was stretched over two drums about 8 inches in diameter, and about 7 feet apart. One of these drums was driven by an electric motor, and caused the belt to revolve around the other, idle, drum. The oscillograph was placed in front of this idling drum, at the correct focal distance to define the spot of light sharply on a film fastened on the drum. This

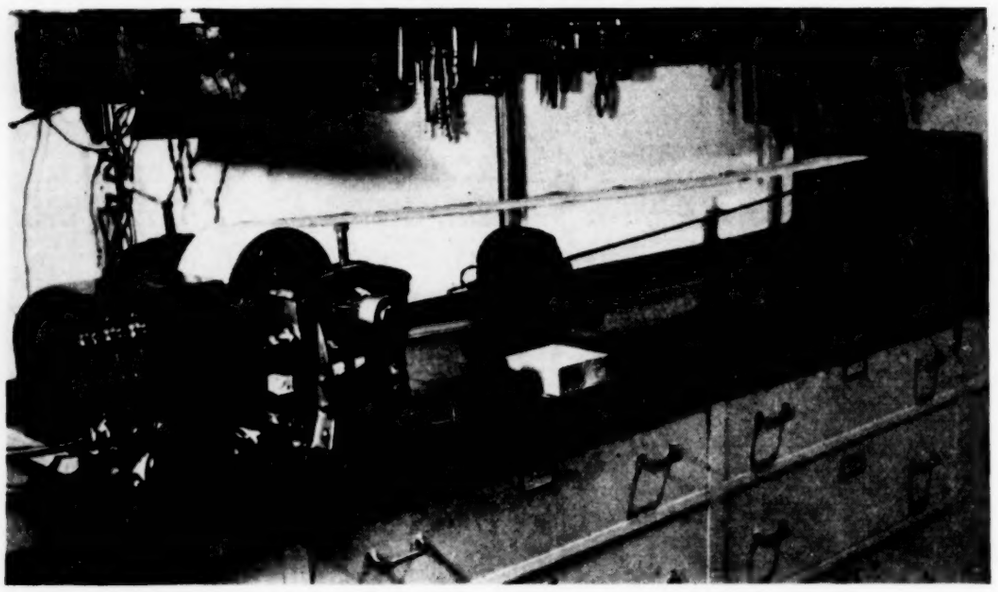

FIG. 1.

same rather hastily constructed belt has been in service now over a period of two years, during which time it has made many thousands of revolutions. It shows little sign of deterioration yet, and is apparently good for a long time. The smooth surface is next to the drums, leaving the cloth surface (wrong side) uppermost. The film can be easily fastened on this by means of a strip of adhesive tape at each end.

Figure 1 shows the belt. At the left stands the oscillograph, in front of the idle drum. The clearance when focused is small, but sufficient. At the right is a box containing the

drum which drives the belt. This drum is itself driven by the motor by means of a leather belt which engages either a pulley on the drum-shaft inside of the box, or the larger pulley to be seen on the extension of the drum-shaft outside of the box. We have therefore two film-speeds available, as follows: low-speed, approximately 11 feet per second, and high-speed, approximately 22 feet per second. So far it has not been necessary to use the higher speed. The highest frequency which it has been necessary to count with the naked eye in our records has been around 4000 dv, and the lower film-speed will separate the individual waves of this frequency to about .033 inch, which is quite sufficient for analysis when the spot of light has been properly focused. Intermediate speeds have been obtained by using a rheostat.

The only trouble experienced with the belt was that of 'walking' laterally along the drums, due to slight non-parallelism of the drum-axes. This was corrected by fitting a simple 'micrometer' adjustment to swing the rear of the driver-drum box slightly. Thus its position could be accurately set by means of a screw so that the belt was equally tight on both sides. When adjusted properly, it may be run indefinitely without the belt changing position in the slightest.

The use of a long belt of this sort has an additional advantage, in taking all vibration away from the oscillograph. The drum that came with the oscillograph originally, fitted into slots in the back, and when driven fast caused the whole instrument to vibrate and rattle. This would in time loosen the tiny mirror from the vibrator ribbons, if it did nothing more serious. Now, in addition to being able to take 14-foot records instead of 10-inch ones, the oscillograph rests quietly on a solid work table in front of the moving film.

The belt is approximately $14\frac{1}{2}$ feet long, and 5 inches wide. It is set up in a dark-room soundproofed from the studio where the singer or player performs. Figure 2 shows a closer view of the belt, the idle drum and its bearings, and the oscillograph in position for recording. The leader end of a narrow film (fastened to the belt with adhesive), has just passed the light window. This light window cannot be seen in the picture, but is in a horizontal plane with the drum-shaft.

Having solved the problem of moving a long film past the oscillograph, it was necessary to find some means of making the exposure. In ordinary cameras this is done by opening and closing a shutter. With our oscillograph, however, it was much more desirable to use no shutter, but to start and stop the exposure by closing and opening the circuit of the incandescent lamp which furnishes the light reflected from the

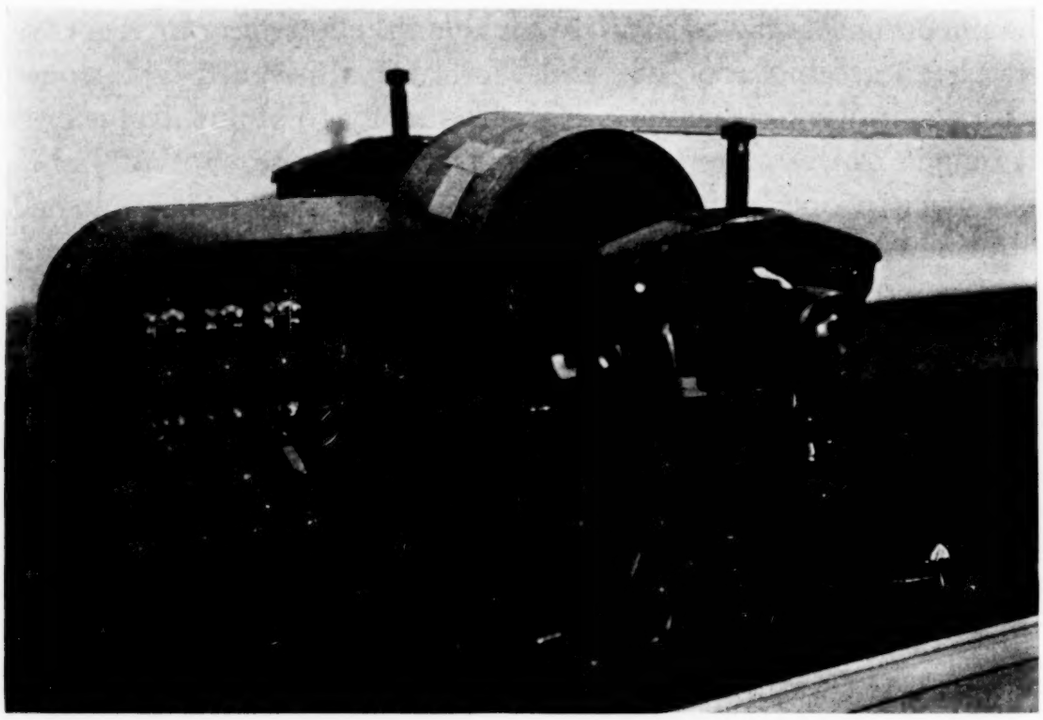

FIG. 2

vibrator mirror to the film. The reason for this is that in order to get records at all at the speeds we needed, it was necessary to flash 7 or 8 volts momentarily on a 4 volt lamp. This increases the intensity of the light quite considerably, particularly in that section of the spectrum to which the photographic film is most sensitive. It is hard on the lamp, though, and so the current should be shut off as soon as the spot of light has been traversed by the length of film. Thus, although the vibrator in the oscillograph is responding constantly to the variations of the sound waves, a record is made only when light is reflected from its mirror to the film.

After trying out several methods without success, this ex-

posure problem was solved by placing only a 10 foot length of film on the belt. This left a gap of $4\frac{1}{2}$ feet with no film. A very thin wire about 16 inches long was fastened on the belt and arranged to slide over two stationary brass arch brushes. This would complete a circuit which would flash a pilot lamp (or give a short audible signal in a telephone receiver), in the studio where the singer or player was performing, at the exact instant when the center of the $4\frac{1}{2}$ foot filmless section was in front of the light window. At the proper time in the rendition of the music, an operator in the studio would then press a telegraph key on one of these flashes and release it on the next flash. This key would control the 8 volts supplied to the oscillograph lamp in the dark-room, and the light reflected from the vibrating mirror would trace a curve on the 10 feet of film. The lamp would come on and go out during the interval of time that the $4\frac{1}{2}$ foot section was passing the light window.

This method worked fairly well, except that it required quite careful concentration on the part of the operator. The flashes occurred every $1\frac{1}{3}$ seconds, at the lower film speed, and the possible error in synchronization was that which $2\frac{1}{4}$ feet of film would allow, which at the lower speed was approximately $\pm$ 1/5 second. If this were exceeded, an overlap would occur at one or both ends of the record. If the operator had nothing to do but attend to his signals, and synchronize his key with any two successive ones, this method would have been satisfactory. However, it was necessary for him to attend also to the sound, so that he could select the proper moment in the duration of the tone to take the record. Also, he could hardly prevent himself from hearing rhythms induced by the music being performed, which would cut across the exposure rhythm with which he had to synchronize. Consequently this method was discarded.

Next we purchased an 'Automatic Drop' relay, of the type which are used for burglar alarms. These consist of a pair of magnets which when energized by current pull down an armature which acts as a trigger to release a spring contact. This contact flies against another, and completes a circuit through

a signal such as a bell, which will continue ringing until shut off by a master switch. The original impulse of current need only be very short, just sufficient to trip the trigger. We used this in the circuit shown in Fig. 3.

When the studio operator is ready to record, he closes the operating key. This sets up a circuit through the magnet coils and the stationary belt brushes, which is completed as

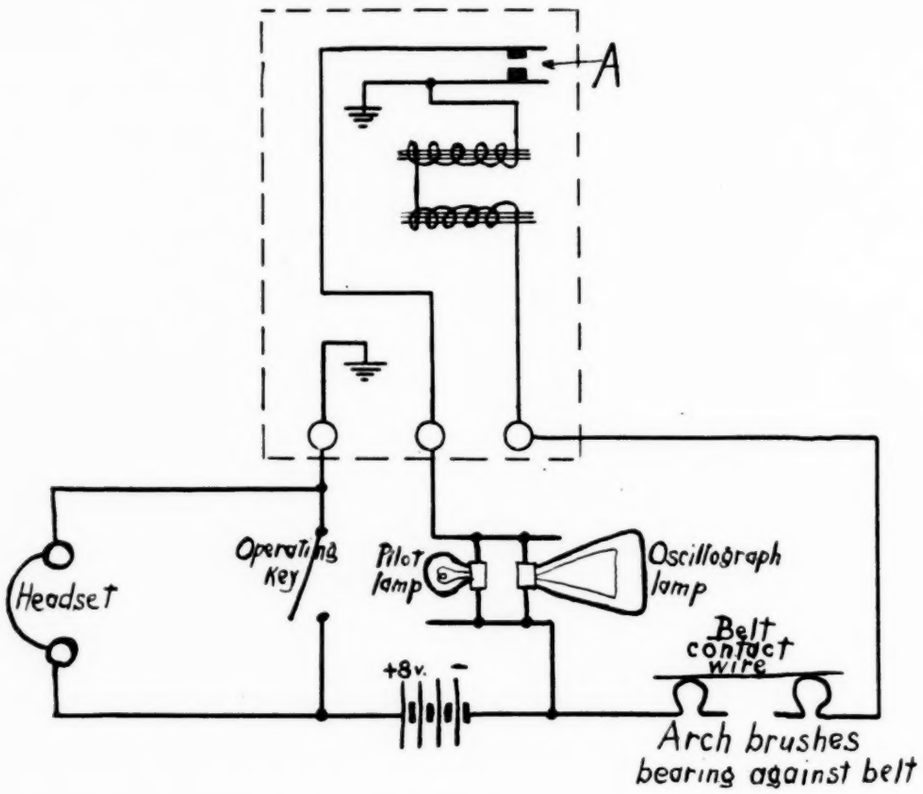

FIG. 3.

soon as the contact wire on the belt next reaches these brushes. When this circuit is completed, the magnets draw down the trigger (not shown), and the contact points at *A* complete a circuit through the key and the oscillograph lamp. The lamp will remain lit as long as the operator holds down the key. A pilot lamp in parallel, and located in the studio, will indicate the interval of time that the oscillograph lamp is on, while a head-set around the key gives the operator preliminary signals at the instants when the belt contact is made, should he desire them.

The advantage of this method is that the operator is re-

lieved of the necessity of synchronizing the beginning of the exposure with a visible or audible signal. He may press in the key at any time, and as soon as the leader end of the film is *next* ready to come before the light window, the light is automatically turned on. There is a possible lag here of nearly $1\frac{1}{3}$ seconds, of course, if the contact has just passed its brushes when the key is closed. By getting into the habit of closing the key about a half second before the time that the exposure is desired to start, the 'probable error' here is cut down greatly.

Although this method was an improvement, there was still considerable opportunity for error, since the operator had to *release* the key with just as much exactness as before. More of his attention was available for the releasing, it is true,

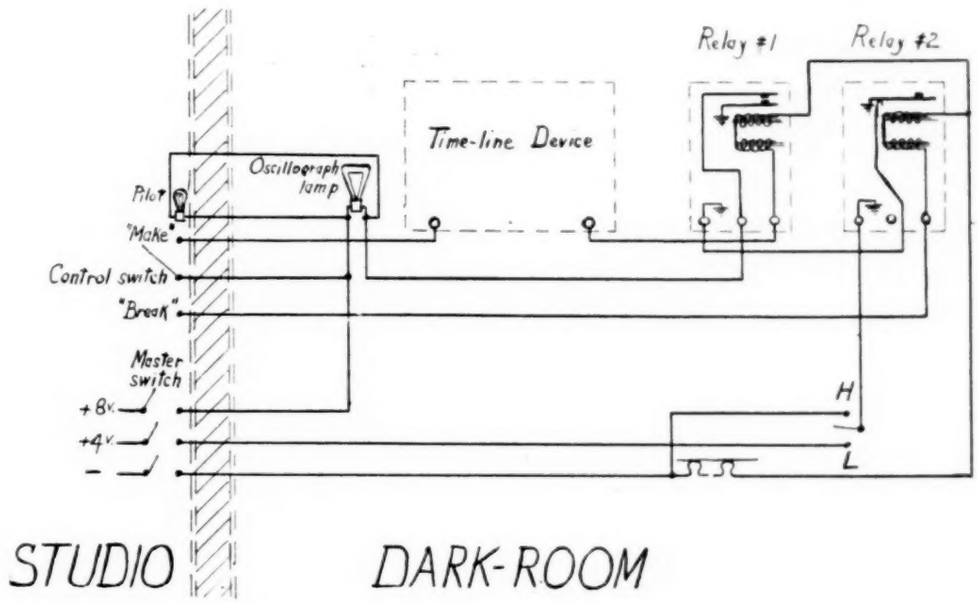

FIG. 4.

but it was still a task of muscular synchronization, which demanded too close attention.

We finally overcame this fault by the use of a second relay, somewhat modified, and by modifying also the relay circuits so as to make the control circuit through the operating key independent of the lamp circuit. Figure 4 shows one of several circuits we used, embodying this method.

The key has now become a two-pole 'control' switch. When the operator is ready to record, he closes this switch in

the up, 'make,' position. This sets up a circuit through the magnets of the time-line device (described elsewhere [2]), the magnets of relay no. 1, and the belt brushes. When this circuit is completed by the belt contact wire, the contacts of relay no. 1 are closed as before and a current flows through the oscillograph lamp, the contacts of relay no. 1, and the contacts of relay no. 2 (which are already closed), and back to the battery through a two-way switch. This switch enables either 8 volts to be used for high-speed photography, or 6 or 4 volts for very low-speed photography or for viewing the waves by means of a revolving mirror. It will be noticed that relay no. 2 is normally in the *closed* position. Its upper contact is not used, and an auxiliary one has been placed against its lower one in such manner that when its trigger is tripped, the circuit will be *opened*. For this reason it is called the 'break' relay. Now as soon as the oscillograph lamp has lit, the pilot lamp indicates this fact to the operator, who immediately closes the control switch in the down, 'break,' position. This sets up another circuit, through the magnets of relay no. 2 and the belt brushes, and this circuit is completed the *next* time the belt contact arrives at these brushes. The magnets of relay no. 2 are then energized, the trigger is tripped, and the circuit is broken, even though the contacts of relay no. 1 are still closed. Thus the lamp has been lit for one complete belt revolution, coming on and going off well within the $4\frac{1}{2}$ foot filmless section. The relays are reset between records by pushing plungers.

This method was a big improvement over the others. However, it was not completely automatic. The operator was still under the necessity of attending to the pilot lamp, and although he no longer needed to synchronize any of his movements with a short signal, he yet had to throw the switch to the down position within a comparatively short time (one belt-revolution) after he saw the pilot lamp light. It was desirable that he be relieved of the necessity of attending to anything except the sound to be recorded, and the reactions

[2] Bartholomew, W. T., An inexpensive means for timing oscillograph records, *Am. J. Psychol.*, 1932, XLIV.

of the subject, in order that he might not miss hearing and noting any chance phenomena that might later be found inexplainable in the photograph. (For example, a sudden 'crack' in the voice.) For this reason the circuit was again improved, so that the operator, when he is ready to record, needs to do only *one* thing, after which the oscillograph lamp is turned on and off automatically. This circuit is given in Fig. 5.

To make a record, the studio-operator closes the control

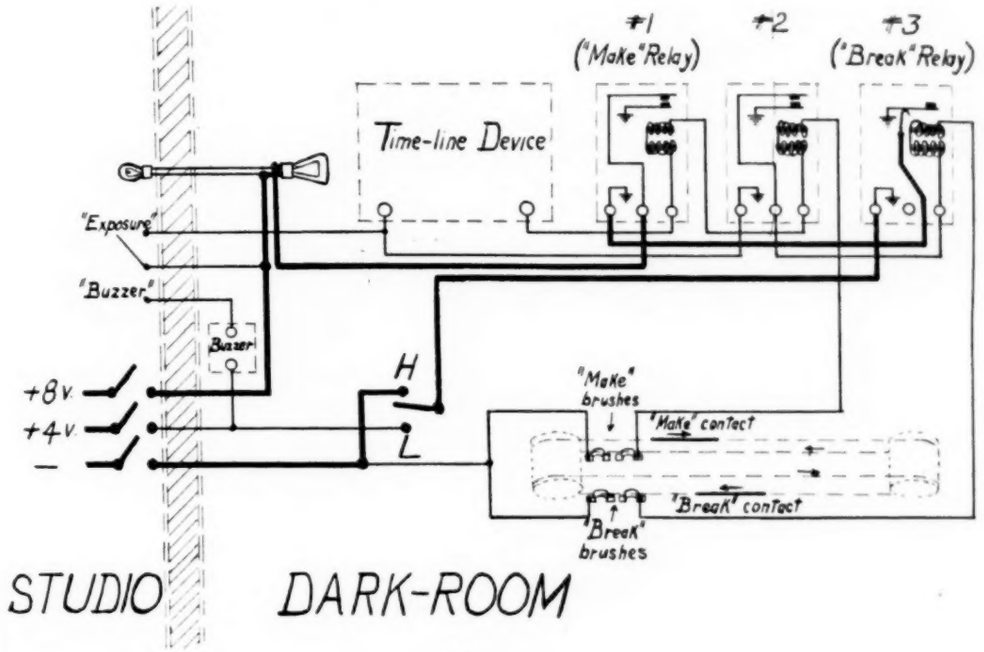

FIG. 5.

switch in the up, 'Exposure,' position, and leaves it there. The down, 'Buzzer,' position is reserved for signaling to the dark-room operator. Two sets of brushes and contact wires are necessary in this method; one to make the lamp circuit, and one to break it. One set must be placed ahead of the other on the belt, so as to prevent simultaneous action. This makes it possible for the control switch to be closed in 'Exposure' position either: (1) after the 'break' contact has passed its brushes and before the 'make' contact has reached its brushes; or (2) after the 'make' contact has passed its brushes and before the 'break' contact has reached its brushes. In the former case, the first relay to operate would be the 'make'

relay, and one belt-revolution later, the 'break' one would operate (as in the previous circuit). In the second case, however, the circuit would be broken by the 'break' relay before it had been made by the 'make' relay, and the lamp would not light at all. In order to prevent this, the current which is to operate the 'break' relay through the 'break' brushes and the contact wire on the belt, is run through the contacts of a third relay (here called no. 2), which contacts are closed by the same circuit that operates the 'make' relay (no. 1). (It will be seen from the diagram that the windings of these two relays are in series.) Thus the 'break' relay cannot operate

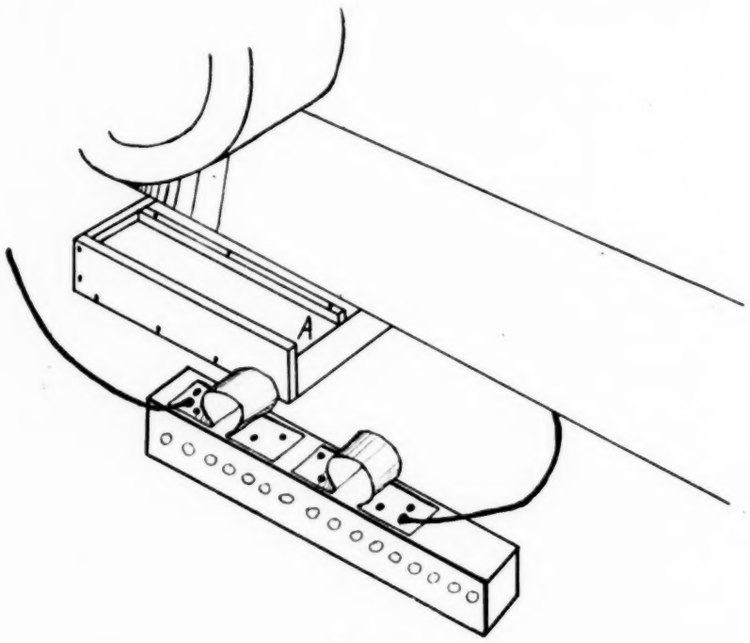

FIG. 6.

until the 'make' relay operates, because its operating circuit is not set up as far as its belt contact until relay no. 2 closes, simultaneously with no. 1.

Therefore no matter at what part of the belt-travel the control switch is closed, the first relay to operate will be the 'make' relay. This will light the lamp. At the same instant, however, relay no. 2 has connected the hitherto broken circuit to the 'break' brushes, and as soon as this circuit is altogether completed by the next passage of the 'break' contact-wire over these brushes, the 'break' relay opens the lamp circuit.

Figure 6 shows one of the pairs of brushes. The two

arches are bent out of brass, and fastened to a strip of celotex board, which helps to deaden vibration. This strip slides into the groove *A* shown in the block behind the left-hand arch. This places the two arches in position under the belt, and bearing on it very close to the point where it rides onto the idle drum.

Figure 7 shows the pair of arches in position. A similar

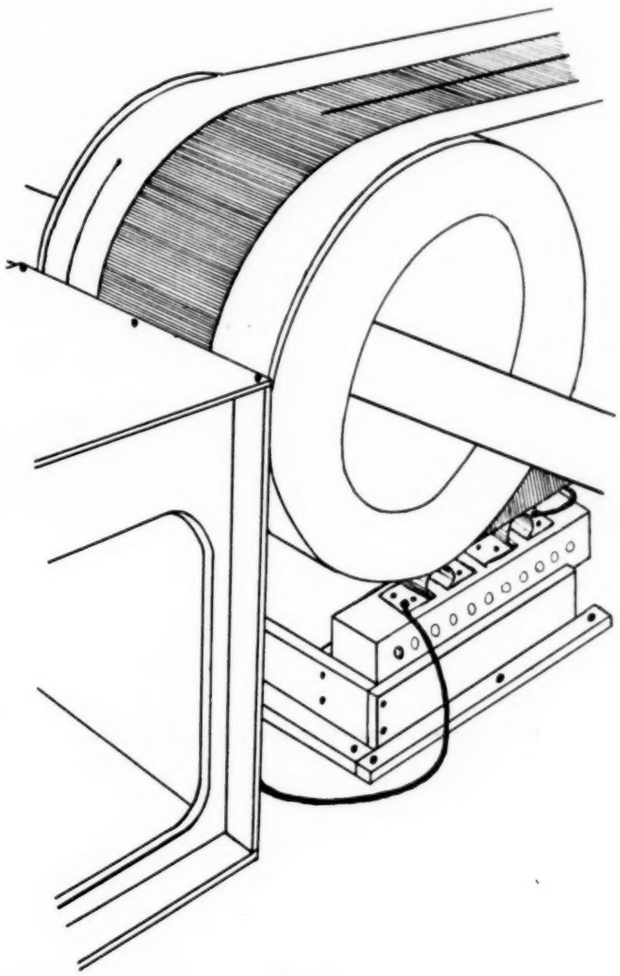

FIG. 7.

pair slide into a similar groove on the other side of the belt, and the belt rests on these four arches. The two sides of the belt have been covered with smooth tapes, of paper, to reduce the sliding friction over the brushes, and on one of these tapes is to be seen a section of one of the contact-wires. The length of these contact wires has been cut down to 12 inches. This leaves about 9 inches for the actual contact, since the arches

are about 3 inches apart. At the higher film-speed, this corresponds to an actual time of only about 1/30 of a second, but this time is sufficiently long to trip the relays. The black line in the center of the belt is a centering line for the film, which is placed in the space between the two paper tapes.

FIG. 8.

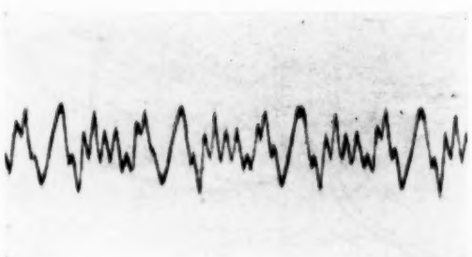

FIG. 9.

Figure 8 shows a corner of the studio. At the right-hand side of the picture is to be seen the control switch, together with two signal lamps. In practice, when a record is to be made, the studio operator waits for a green light signal from the dark room. When he sees it, all is in readiness for a record. At the particular time that he wishes to photograph the tone, he closes the control switch to the 'Exposure' position. The oscillograph lamp is automatically lit at a time varying up to $1\frac{1}{3}$ seconds after he throws the switch, and is automatically

shut off after an interval corresponding to the distance between the two contact wires on the belt. A red pilot light indicates to the studio operator the interval of time that the oscillograph lamp is on. After this pilot lamp has gone out, he may open the switch again, although if left closed it does nothing more than click the relays which have already been tripped. The oscillograph lamp is safely out, and cannot be lit again until the relays are reset.

The dark-room operator is supplied with a pair of headphones, to be seen in Fig. 1, which are shunted around the vibrator. These enable him to listen in on the studio, and to hear the sound as it is being photographed. He waits until he hears all the relays trip, or he may also watch the light shine on the film until it goes out. He then shuts off the belt motor, takes off the exposed film and places it in a light-proof can, fastens a new length of film on the belt, numbers it according to the number signalled to him by the buzzer, re-sets the relays and the time-line device, and turns on the belt motor. The switch which controls the belt motor also lights the green lamp signal in the studio, and the studio operator, after checking the amplifier meters, proceeds with the next record.

If the next record is to be made quite immediately, so that there is not time to change films, it is possible for the dark-room operator to close a biassing switch which puts sufficient DC through the oscillograph vibrator to move the zero-position of the spot of light so that another wave may be photographed alongside of the first one on the same film strip. This, together with the re-setting of the 3 relays, can be done in 2 or 3 seconds. If the cost of film needs to be considered, this method is of value, although of course the permissible amplitude is halved in this case. It is also of value where it is desirable to have two waves juxtaposed for purposes of comparison, as when the same note occurs twice, near together, in the same composition.[3]

The circuit we are now using has still another advantage over its predecessors. The 'break' contact-wire may be

[3] It must be emphasized, however, that the drawing of conclusions from mere visual comparison of sound waves is subject to error. Little can be told about the timbre of a tone from the graph of the wave until it is subjected to harmonic analysis.

placed anywhere on the belt, and if 5-foot records are desired, or only 1-foot ones, it can be set so that the lamp is lit only as long as absolutely necessary, instead of a whole belt-revolution in each case, as before. A certain lag must be allowed for the lamp to come up to full brilliancy before the film reaches the light window, but no lag is necessary at the other end. Recently we have taken a large number of 3-foot records (sufficiently long to show at least one complete vibrato cycle in a tone). Suppose we allow as much as 2 feet for the lamp to come up to brilliancy. We are then able to set the 'break' contact-wire only 5 feet from the 'make.' Thus our lamp is turned on only about 35% as long as with the previous method. This can mean a considerable saving in bulbs, especially when 7 or 8 volts must be flashed on a 4 volt lamp. However, the life of these lamps is really remarkable. They have been much improved from the earlier models, by the Westinghouse Company. With the older circuit, which required the lamp to be on $1\frac{1}{3}$ seconds per exposure, we have taken hundreds of such exposures at over-voltages of 6, 7, and 8 volts without burning out the bulb. In fact, one bulb performed recently at such over-voltages for a series of nearly 600 records, besides being used for low-voltage viewing. It has not burned out yet, although it has developed a flicker when first heating up. The real limitation of these lamps is the cutting down of their light-production from blackening. This is caused by the deposition of filament-material on the inside surfaces of the glass, and is much accelerated when the lamp is burned at over-voltages. When this blackening reaches a certain point, records are no longer possible.

The primary advantage of the circuit, however, is that it frees the operator from as much detail as possible.

The method as it stands has at least one inherent fault; namely, the studio operator cannot know just exactly when his exposure is going to start. He may catch it instantly, or it may be delayed as much as $1\frac{1}{3}$ seconds after throwing the switch. It may be argued that this is a distinct disadvantage in cases where the tone lasts only a short while. The answer to this is that it is extremely unsafe to draw conclusions from

records of such tones. Previous studies in this and other laboratories have shown the important part played by the method of attack, 'scooping,' etc. For instance, a tone which lasts only one second, might have half or more of that second taken up by the preparatory scoop, and it would be impossible for the operator to expose with such precision that he would get only the final quality and none of the preparatory quality, even if the apparatus would always respond immediately. Furthermore, the vibrato, in the case of the human voice, is frequently not set up immediately within the first second. For studies of tone-quality, it is necessary to have the tone sustained long enough to settle down into an approximately steady state of vibration, with pitch, intensity, and timbre modified only by the slight and regularly recurring variations of the vibrato cycles.

A short description of the rest of the apparatus may be helpful, also. The sound waves are picked up by a microphone, and amplified sufficiently to affect the vibrator of the oscillograph. Formerly a carbon microphone was used, but the characteristic 'frying' hiss of background noise destroyed the value of the records for quantitative measurement of the high partials. This microphone was superseded by a condenser-type microphone, which is built on a different principle, and combines a greater fidelity of response with freedom from any carbon noise. In order to minimize the possibility of distortion due to echoes impinging on the microphone, the walls and ceiling of the studio have been covered with Celotex, and the floor with carpet.

With the microphone is associated a system of three amplifying units, which build up the very weak impulse generated in the microphone to a strength capable of actuating the vibrator. The overall amplification of the condenser microphone amplifier and intermediate amplifier is approximately 4500. The output leads from the power amplifier are led through the wall of the studio to the oscillograph in the darkroom, where they pass through a specially constructed vibrator. The whole set-up from microphone to vibrator was designed as a unit for the Peabody by the Westinghouse Company.

The power amplifier is equipped with a meter which gives a visible indication of distortion caused by the grids taking current. The vibrator is the result of recent research by the Westinghouse Company in an attempt to combine higher-frequency response with reasonable sensitivity. Its response curve is practically flat to 3200 dv, shows over 50 percent deflection at 6000 dv, and 25 percent at 10,000 dv. The response curve of the amplifiers is flat from 40 dv to 7000 dv, and shows 91 percent response at 10,000 dv.[4] An auxiliary vibrator, of much higher sensitivity (but lower frequency response), is used to record the time-line already mentioned.

As to the photographic end, we have gotten good results by using unperforated moving picture negative film. Most of our recording, however, is now done on a special recording paper. Extreme caution must be taken with the handling of this paper, both before exposure and after, and in the developing process. It is extremely sensitive and easily fogged.

In Fig. 1 is to be seen a dark-room light, which is fitted with a Wratten Series 3 Safelight. This gives the dark-room operator a faint green light, enough to see to change films and reset the 3 relays. (These relays can be seen to the left of the lamp.)

It is necessary to keep the optical system of the oscillograph clean, and it is advisable to cover the lamp with dark material or black paint, except that area which transmits light to the vibrator-mirrors. There are several adjustments for the optical system, and several on the amplifiers, all of which need to be carefully checked. In fact, as the result of several years of experience we can warn other investigators to check *every single detail:* condition of storage batteries and *B* batteries, emission of tubes, dark-room conditions, optical system, freshness of film, freshness of developer, etc., before proceeding with records. Any one of fifteen or twenty items may be responsible for failure. Figure 9 shows the type of record obtainable when every detail is checked. It is of the vowel '(n)ah,' sung loudly by an untrained tenor voice at a pitch of

[4] The designing of the amplifying units and the vibrator is the work of Mr. H. T. Rights, Oscillograph Engineer in the Westinghouse Co., who has coöperated with us from the beginning.

262 dv. The 3d and 12th partials are quite prominent, corresponding to frequencies of 786 and 3144 dv.

One can better comprehend the need of conserving as much contrast as possible when he realizes that the little spot of light has passed through two prism reflections, one mirror reflection, and three lenses in its passage from the little lamp to the film; and that frequently it sweeps across the film surface at a speed equal to that of a fast airplane, which means that it must affect a linear inch of the photographic emulsion in less than one four-thousandth part of a second.

Summary.—Apparatus has been described for taking long oscillograph records at high film speeds. The method comprises a belt driven by a drum over another, idle, drum, in front of which an oscillograph is placed, so that the light from the oscillograph may trace a record on a film fastened on the belt. Automatic means is described for exposing given lengths of film by remote control from the sound-proofed studio. Associated apparatus is described.

The complete set-up has given quite satisfactory results. In a recent series of over 700 voice records, about 2500 feet of film was exposed. Minor repairs and adjustments were necessary from time to time, of course, but as a whole it performed remarkably well. As a matter of fact, several singers have expressed surprise when told that their tone had been photographed. They are unable to hear or see anything that would give them a clue as to what instant the exposure is made, which tends to lessen their 'microphone stage-fright.'

(Manuscript received January 13, 1932)

THE EFFECT OF HIGH AND LOW FEMALE SEX HORMONE CONCENTRATION ON THE TWO-POINT THRESHOLD OF PAIN AND TOUCH AND UPON TACTILE SENSITIVITY [1]

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Much recent physiological and psychological work on animals has been done in relation to the correlation between sex hormone levels and motor activity, whether in connection with learning (Tsai, **5**), with spontaneous activity (Richter, **3**), or with reflex activity (Herren and Haterius, **2**). It seems probable from the conclusions drawn by these authors that similar results may be expected in the sensory field. Obviously the human is the best subject for such experiments.

With these considerations in mind, two-point thresholds for both pain and touch and tactile sensitivity were taken within five days prior to the onset of menses, within three days following the cessation of menses, and on a day two weeks following the onset of the last menses. The five subjects were young women between the ages of twenty-four and thirty-four. In all, eleven complete menstrual cycles were tested.

The apparatus for two-point discrimination was so constructed that a counter weight offset the weight of the stimulus points. The latter were allowed to press with a weight equivalent to twenty grams. The final reading was the average of ten readings approaching the limen from above and ten readings approaching the limen from below. Constant points of stimulation were insured by always placing the non-varying stimulus point on the point of juncture of two superficial vessels and stimulating along a line drawn between this and another point similarly located. The volar surface of the

[1] The author wishes to express his gratitude to Professor Lee Edward Travis in whose laboratory this work was done.

lower fore-arm was used in all subjects. Aesthesiometric measurements were made by means of a series of graduated hairs. The graduations were determined on an analytical balance by noting how many milligrams the hair could resist without bending. Stimulation for tactile sensitivity was always made at a central point on the median interdigital surface of the second phalanyx of the middle finger. The right arm and hand were always used.

TABLE I

THE THRESHOLDS FOR TWO-POINT TOUCH AND PAIN DESCRIMINATION AND FOR TACTILE SENSITIVITY AT THE PRE-, POST-, AND INTERMENSTRUAL PERIODS

		Two-point touch threshold in mm			Two-point pain threshold in mm			Tactile sensitivity in mgms		
Subject	Cycles	Premenstrual period	Postmenstrual period	Intermenstrual period	Premenstrual period	Postmenstrual period	Intermenstrual period	Premenstrual period	Postmenstrual period	Intermenstrual period
F-H....	3	21.6	27.9	28.8	18.6	24.9	24.7	.04	.08	.09
F-R....	4	24.0	29.9	30.8	25.7	32.0	32.4	.11	.30	.30
F-M...	2	19.8	25.2	27.7	14.1	26.4	29.0	.07	.10	.08
E-K...	2	23.4	25.9	23.3	22.7	25.4	24.0	.09	.10	.20
P-T....	1	—	—	—	—	—	—	.10	.21	.20

Table I shows the two-point thresholds in millimeters and the tactile sensitivity in milligrams for the three periods of recording. It will be seen that the premenstrual readings show considerably lower thresholds than do the post-menstrual readings. Intermenstrual readings more closely approximate postmenstrual.

By a biological assay it has been shown recently by Frank (1), that in over two hundred normal women, the female sex hormone (follicular hormone) builds up from a low level to a peak in the seven days preceding menses and that the first day of menstruation initiates a sudden fall in this level as the hormone escapes from the circulation by way of the kidneys and menstrual flow. There is another slight rise in the blood level at about the seventeenth day of the intermenstrual period. While the blood of our subjects was not extracted and tested to absolutely determine its potency in regard to hormone content it is assumed that our subjects fell into the

normal group, as defined by Frank's test, since all of them were regular in their cycles and suffered none of the abnormalities of menstruation. This lowering and heightening of the two-point thresholds and the limen for tactile sensitivity corresponding respectively to an increase and decrease in sex hormone concentration in the blood indicates that the hormone increases the sensitivity of central nervous system cells to incoming impulses. The mechanism of this influence is unknown. That the equilibrum between higher and lower motor levels is shifted corresponding to fluctuations in sex hormone concentration has been demonstrated in rats by Herren and Haterius (**2**), who showed an increase in the inhibitory action of the upper motor neurone on lower neurone arcs during oestrus and a release of this action during dioestrus. In work to be published elsewhere Herren and Haterius have further shown that the mechanism for this phenomena is the sympathetic system over which impulses pass to the cord and hence to higher levels. In our human subjects an attempt was made to reproduce the results obtained on normal rats by recording achilles and patellar reflex times during the premenstrual and and postmenstrual periods. The apparatus and method have been fully described elsewhere (**4**). However, in four subjects no change in reflex time was found to be associated with changes in hormone level. This may have several explanations. The more evident one is that physiologically changes in hormone level are not of equal importance in lower animals and human beings and secondly, that the human being, by virtue of a more complex nervous structure, is not so much a slave to internal or external environment as are other mammals.

Summary

1. In five normal women followed through eleven menstrual cycles a high concentration of female sex hormone (follicular fluid) in the blood corresponded with a lowered threshold for two-point touch and pain descriminations and for tactile sensitivity, the opposite was also true.

2. For similar conditions no change in reduced reflex time could be demonstrated.

(Manuscript received January 29, 1932)

References

1. Frank, R. T., The Female Sex Hormone, Charles C. Thomas, Baltimore, 1929, 177–190.
2. Herren, R. Yorke and Haterius, H. O., The relation of ovarian hormones to electromyographically determined achilles reflex time, *Amer. Jour. Physiol.*, 1931, **96**, 214–220.
3. Richter, Curt P., Animal behavior and internal drives, *Quart. Rev. Biol.*, 1927, ii, 307–343.
4. Travis, L. E. and Herren, R. Yorke, The relation of electrical changes in the brain to reflex activity, *Jour. Comp. Psychol.*, 1931, XII, 23–39.
5. Tsai, L. S., Sex glands and adaptive ability, *Science*, 1930, LXXXI, 106–108.

SENSATION CUES TO MOISTURE

BY C. E. LAUTERBACH AND REX E. CROUSER
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In speaking of the skin senses Woodworth (Psychology, Revised, p. 317) makes the statement that "Moist is a blend of touch and cold." This statement suggested the possibility of demonstrating temperature as a moisture cue by combining wetness and dryness with variable temperature conditions and noting the amount of error involved in judgments of wetness and dryness by tactile discrimination. The wet-dry conditions were conceived to be almost ideally present in combinations of water and mercury. After considerable preliminary investigation an experimental set-up was effected as follows:

1. Four beakers with a capacity of 1000 ccs each were filled with water and placed in an electrically heated water bath set to maintain a temperature of 37° C. Four other beakers were placed in a bath set to maintain a temperature of 20° C.

2. Eight thistle tubes measuring 3.5 cm across the top were cut off and sealed 8 cm from the bowl. These were half filled with mercury and suspended one each in the beakers. Suspension was effected by cutting a hole 3 cm in diameter in a piece of heavy asbestos board (13 cm × 13 cm) and inserting the tube in the hole. A column of mercury thus extended into the water and by conducting the heat from the water to the bowl a fairly constant temperature was maintained.

3. Into two of the tubes carrying a temperature of 37° C water was poured to a depth of approximately 3 mm. The same was done with two tubes carrying a temperature of 20° C. The tubes were identified by the letters *A*, *B*, *C*, and *D* with a plus sign for wetness and a minus sign for dryness. The following conditions were obtained:

Tube *A* Wet (+) 37° C (*H*)
B Dry (−) 37° C (*H*)
C Wet (+) 20° C (*L*)
D Dry (−) 20° C (*L*)

The tubes were used in combinations as follows:

AD Wet 37° C; Dry 20° C
BC Wet 20° C; Dry 37° C
BD Dry 37° C; Dry 20° C
AC Wet 37° C; Wet 20° C
CD Wet 20° C; Dry 20° C
AB Wet 37° C; Dry 37° C

Two identical sets of beakers were provided which could be used alternately. While one set was being used the other was in the bath regaining its temperature. Each set was used for a period of approximately ten minutes at a time with a maximum temperature variation of about 1° C.

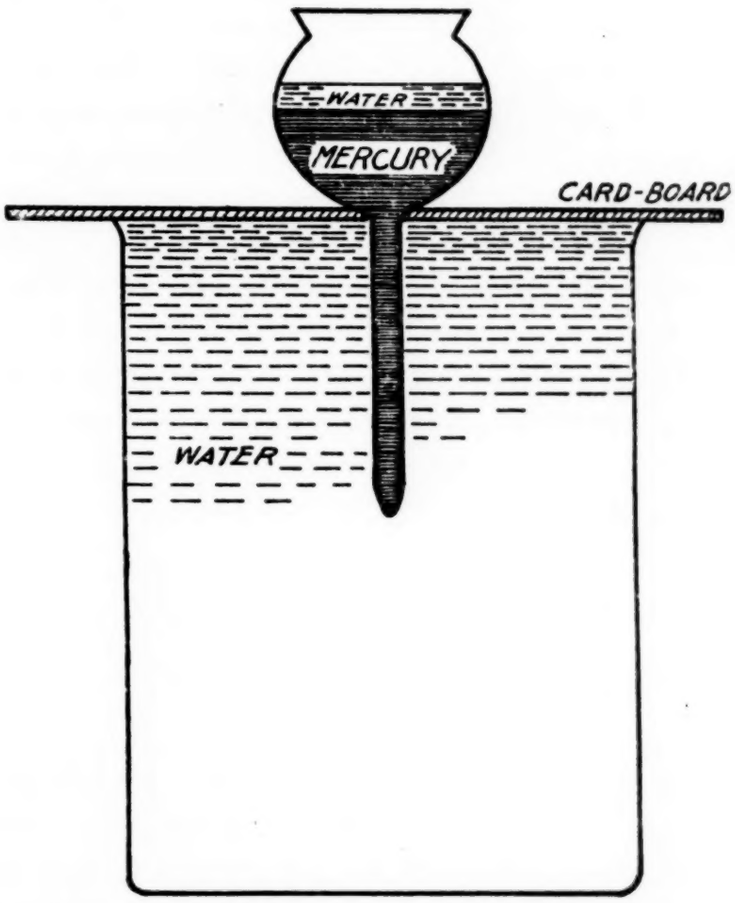

FIG. 1. Apparatus used in experimenting in sensation cues to moisture.

4. The subject was provided with rubber gloves from which the forefingers had been cut. He was seated at a table with his arms through a screen and then given the following typewritten instructions:

"This is an experiment in sensation to determine one of the cues to wetness or moisture. Certain substances will be presented to you for tactile inspection and you will be asked to state whether they feel wet or dry. There is no trickery about the experiment; it is serious in intent and scientific in procedure. Follow the instructions of the experimenter very carefully. Do not ask questions. The results of the experiment will be made available to you at a later time."

It became necessary to supplement these instructions with the directions to hold the forefingers perfectly still and to make no exploratory movements during the experiment.

5. The four beakers *A*, *B*, *C*, *D* were placed on the table upon a small revolving platform. The forefingers of the subject were simultaneously immersed in two of the pools and the question was asked, "Which one is wet?" The response was right, left, both or neither but no instructions were given, the nature of the response being left to the initiative of the subject. A blank for recording responses was provided. After each immersion both of the subject's fingers were wiped with a dry towel. Twenty trials were given on each of the six combinations, one trial for each combination in the order *AD*, *BC*, *CD*, *AB*, *BD*, *AC*. The beakers were changed four times to assure constant temperature. At each change the relative positions of the beakers on the table were changed to prevent the establishment of memory cues, as follows:

$$\text{Position 1}\ \frac{AB}{CD} \qquad \text{Position 3}\ \frac{BA}{CD}$$

$$\text{Position 2}\ \frac{DB}{CA} \qquad \text{Position 4}\ \frac{AC}{DB}$$

Following Woodworth, the experiment was begun on the theory that a relatively low temperature yielded a wetness cue. The first conclusion revealed by the results is that while this assumption is correct in the majority of cases, there are clearly defined exceptions. This fact dawned upon the experimenters as a complete surprise. It is, however, clearly demonstrated by cases 8 and 9 where 78 percent of the judgments favor the presence of wetness in combination with the

TABLE I *

Case No.		$\frac{AD}{HL}$	$\frac{BC}{HL}$	$\frac{BD}{HL}$	$\frac{AC}{HL}$	Totals of rows					$\frac{CD}{LL}$	$\frac{AB}{HH}$	Totals of rows			
		+ −	− +	− −	+ +	*H*+	*L*+	*B*+	*N*+		+ −	+ −	+	−	*B*	*N*
1	*H*	0	2	0	3					+	1	1				
	L	12	16	14	15					−	3	1				
	B	4	2	2	1					*B*	16	2				
	N	4	0	4	1	5	57	9	9	*N*	0	16	2	4	18	16
2	*H*	9	5	12	0					+	7	9				
	L	11	15	8	20					−	13	11				
	B	0	0	0	0					*B*	0	0				
	N	0	0	0	0	26	54	0	0	*N*	0	0	16	24	0	0
3	*H*	0	0	0	3					+	3	2				
	L	20	20	20	17					−	1	2				
	B	0	0	0	0					*B*	16	1				
	N	0	0	0	0	3	77	0	0	*N*	0	15	5	3	17	15
4	*H*	3	0	1	0					+	7	0				
	L	14	13	9	18					−	0	2				
	B	2	7	6	2					*B*	13	8				
	N	1	0	4	0	4	54	17	5	*N*	0	10	7	2	21	10
5	*H*	0	1	2	0					+	6	2				
	L	17	16	9	18					−	0	4				
	B	2	3	8	1					*B*	12	8				
	N	1	0	1	1	3	60	14	3	*N*	2	6	8	4	20	8
6	*H*	5	6	7	4					+	7	3				
	L	10	12	11	14					−	8	10				
	B	5	2	1	2					*B*	4	5				
	N	0	0	1	0	22	47	10	1	*N*	1	2	10	18	9	3
7	*H*	13	12	11	12					+	6	3				
	L	6	8	9	8					−	3	2				
	B	0	0	0	0					*B*	1	12				
	N	1	0	0	0	48	31	0	1	*N*	10	3	9	5	13	13

* The table shows the number of wet-dry judgments rendered in six comparisons of twenty trials each of various combinations of temperatures, wetness and dryness. The letters *AD, BC, BD, AC, CD,* and *AB* represent combinations of temperature and wetness as follows:

A..... wet 37° C.
B..... dry 37° C.
C..... wet 20° C.
D..... dry 20° C.

The letters *H, L, B,* and *N* stand for High, Low, Both and Neither respectively. The plus sign (+) indicates wetness; the minus sign (−), dryness. All judgments are rendered with reference to the question "Which one is wet?" The table is read: Subject No. 1, in the combination *AD*, rendered no judgments in favor of wetness when the temperature was 37° C (*H*) and wetness was present (+); 12 judgments in favor of wetness, when the temperature was 20° C (*L*) and wetness was not present (−); he rendered 4 judgments that both (*B*) items in the comparison were wet when in fact one was wet and one was dry; he rendered 4 judgments that neither (*N*) item was wet when in fact one was wet and one was dry.

TABLE I—*Continued*

Case No.		$\frac{AD}{HL}$	$\frac{BC}{HL}$	$\frac{BD}{HL}$	$\frac{AC}{HL}$	Totals of rows					$\frac{CD}{LL}$	$\frac{AB}{HH}$	Totals of rows			
		+ −	− +	− −	+ +	$H+$	$L+$	$B+$	$N+$		+ −	+ −	+	−	B	N
8	H	16	17	17	13					+	7	4				
	L	3	3	1	5					−	1	4				
	B	1	0	0	1					B	0	12				
	N	0	0	2	1	63	12	2	3	N	12	0	11	5	12	12
9	H	13	16	16	18					+	7	7				
	L	7	4	4	2					−	9	8				
	B	0	0	0	0					B	0	3				
	N	0	0	0	0	63	17	0	0	N	4	2	14	17	3	6
10	H	11	9	15	8					+	11	7				
	L	9	11	5	12					−	9	13				
	B	0	0	0	0					B	0	0				
	N	0	0	0	0	43	37	0	0	N	0	0	18	22	0	0
11	H	6	4	6	9					+	7	6				
	L	8	14	12	8					−	3	3				
	B	0	0	0	0					B	8	3				
	N	6	2	2	3	25	42	0	13	N	2	8	13	6	11	10
12	H	9	6	11	7					+	10	5				
	L	6	8	4	5					−	4	4				
	B	5	5	2	6					B	4	10				
	N	0	1	3	2	33	23	18	6	N	2	1	15	8	14	3
13	H	10	11	11	7					+	0	0				
	L	9	8	9	5					−	1	0				
	B	1	1	0	0					B	17	19				
	N	0	0	0	8	39	31	2	8	N	2	1	0	1	36	3
14	H	8	4	5	3					+	8	9				
	L	2	11	5	9					−	3	3				
	B	6	4	5	8					B	8	6				
	N	4	1	5	0	20	27	23	10	N	1	2	17	6	14	3
15	H	2	2	0	1					+	2	2				
	L	17	17	18	16					−	2	1				
	B	1	1	2	3					B	16	6				
	N	0	0	0	0	5	68	7	0	N	0	11	4	3	22	11
16	H	0	0	0	0					+	6	2				
	L	20	20	20	20					−	12	1				
	B	0	0	0	0					B	2	0				
	N	0	0	0	0	0	80	0	0	N	0	17	8	13	2	17
17	H	1	0	3	0					+	4	0				
	L	17	18	17	19					−	3	2				
	B	2	2	0	0					B	13	15				
	N	0	0	0	1	4	71	4	1	N	0	3	4	5	28	3
18	H	0	0	1	0					+	3	0				
	L	20	20	19	20					−	0	0				
	B	0	0	0	0					B	17	0				
	N	0	0	0	0	1	79	0	0	N	0	20	3	0	17	20
19	H	1	0	0	0					+	6	3				
	L	18	20	18	20					−	1	1				
	B	0	0	1	0					B	13	0				
	N	1	0	1	0	1	76	1	2	N	0	16	9	2	13	16

TABLE I—*Continued*

Case No.		$\frac{AD}{HL}$	$\frac{BC}{HL}$	$\frac{BD}{HL}$	$\frac{AC}{HL}$	Totals of rows					$\frac{CD}{LL}$	$\frac{AB}{HH}$	Totals of rows			
		+ −	− +	− −	+ +	*H*+	*L*+	*B*+	*N*+		+ −	+ −	+	−	*B*	*N*
20	*H*	5	7	14	2					+	11	8				
	L	15	12	6	18					−	4	11				
	B	0	1	0	0					*B*	5	1				
	N	0	0	0	0	28	51	1	0	*N*	0	0	19	15	6	0
21	*H*	8	14	9	2					+	5	12				
	L	12	6	11	18					−	14	8				
	B	0	0	0	0					*B*	1	0				
	N	0	0	0	0	33	47	0	0	*N*	0	0	17	22	1	0
22	*H*	1	4	1	1					+	9	10				
	L	18	15	19	14					−	4	6				
	B	1	1	0	5					*B*	7	3				
	N	0	0	0	0	7	66	7	0	*N*	0	1	19	10	10	1
23	*H*	6	2	6	3					+	8	8				
	L	14	18	13	17					−	8	3				
	B	0	0	0	0					*B*	4	0				
	N	0	0	1	0	17	62	0	1	*N*	0	9	16	11	4	9
24	*H*	3	0	0	2					+	6	2				
	L	17	20	20	17					−	1	0				
	B	0	0	0	0					*B*	13	0				
	N	0	0	0	1	5	74	0	1	*N*	0	18	8	1	13	18
25	*H*	4	5	2	3					+	13	11				
	L	16	15	18	17					−	7	9				
	B	0	0	0	0					*B*	0	0				
	N	0	0	0	0	14	66	0	0	*N*	0	0	24	16	0	0
26	*H*	8	16	12	19					+	9	3				
	L	5	2	5	1					−	6	6				
	B	7	0	1	0					*B*	3	10				
	N	0	2	2	0	55	13	8	4	*N*	2	1	12	12	13	3
27	*H*	8	10	14	11					+	2	5				
	L	10	9	4	7					−	7	8				
	B	0	0	2	2					*B*	10	6				
	N	2	1	0	0	43	30	4	3	*N*	1	1	7	15	16	2
28	*H*	11	4	8	10					+	8	6				
	L	8	14	12	9					−	8	4				
	B	1	2	0	1					*B*	2	10				
	N	0	0	0	0	33	43	4	0	*N*	2	0	14	12	12	2
29	*H*	9	6	8	6					+	8	17				
	L	11	14	12	14					−	12	3				
	B	0	0	0	0					*B*	0	0				
	N	0	0	0	0	29	51	0	0	*N*	0	0	25	15	0	0
30	*H*	5	9	4	8					+	6	2				
	L	11	10	10	8					−	6	8				
	B	2	1	3	2					*B*	5	3				
	N	2	0	3	2	26	39	8	7	*N*	3	7	8	14	8	10
31	*H*	4	1	2	1					+	6	2				
	L	8	16	16	18					−	9	6				
	B	1	0	1	0					*B*	4	5				
	N	7	3	1	1	8	58	2	12	*N*	1	7	8	15	9	8

TABLE II

SHOWING THE 'TOTALS OF ROWS' IN TABLE I IN TERMS OF PERCENTAGE

Case No.	*H*+	*L*+	*B*+	*N*+	+	−	*B*	*N*
1	6	72	11	11	5	10	45	40
2	32	68	0	0	40	60	0	0
3	4	96	0	0	12	7	43	38
4	5	68	21	6	17	5	53	25
5	4	75	17	4	20	10	50	20
6	28	59	12	1	25	45	23	7
7	60	39	0	1	23	12	33	32
8	78	15	3	4	28	12	30	30
9	78	22	0	0	35	43	7	15
10	54	46	0	0	45	55	0	0
11	30	53	0	17	33	15	27	25
12	41	29	23	7	38	20	35	7
13	49	38	3	10	0	3	90	7
14	25	34	29	12	43	15	35	7
15	6	85	9	0	10	7	55	28
16	0	100	0	0	20	32	5	43
17	5	89	5	1	10	13	70	7
18	1	99	0	0	7	0	43	50
19	1	95	1	3	23	5	32	40
20	35	64	1	0	47	38	15	0
21	41	59	0	0	43	55	2	0
22	9	82	9	0	48	25	25	2
23	22	77	0	1	40	27	10	23
24	6	93	0	1	20	2	33	45
25	18	82	0	0	60	40	0	0
26	68	17	10	5	30	30	33	7
27	54	37	5	4	17	38	40	5
28	41	54	5	0	35	30	30	5
29	36	64	0	0	62	38	0	0
30	32	49	10	9	20	35	20	25
31	10	72	3	15	20	37	23	20

higher temperature; and is strongly suggested by cases 7 and 26 where 60 percent and 68 percent respectively of the judgments favor the presence of wetness in combination with the higher temperature. Notes taken at the time of the experiment indicate the same fact. For example: "You can feel water better when it's warm." "The warm ones felt wet." "I could tell that some of them were wet because they were warm." It is evident, then, that a warm temperature serves as a moisture cue for some individuals.

If we accept 70 percent of judgments favoring wetness in

combination with either high or low temperature, as sufficient to indicate a definite cue, we find fifteen cases out of thirty-one which show a well defined tendency to perceive moisture in terms of temperature. These fifteen cases are Nos. 1, 3, 5, 8, 9, 15, 16, 17, 18, 19, 22, 23, 24, 25, and 31. Of these, two cases (8 and 9) perceive moisture by a warm cue; thirteen cases, by a cold cue. These conclusions are based on the four HL combinations with the wet-dry condition variable.

If we examine the remaining cases we find other evidences of a definite temperature cue but it is difficult to compare such evidence with any sort of common measure. Case No. 2 shows 68 percent of the judgments favoring low temperature as a perception cue, not quite enough to satisfy our criterion of 70 percent. But if we turn to the right half of Table 1, where the temperatures are kept constant in the two combinations, we find 40 percent of the judgments favoring wetness and 60 percent dryness. In other words, when the temperature comparison is lacking the subject's perception of moisture is reduced to guessing.

In case No. 4 there is likewise a 68 percent judgment in favor of low temperature, slightly less than our criterion, but when we examine the *LL-HH* combinations we find 100 percent (7+13, Table 1) of the judgments favoring wetness in one or both pools when the temperature was low and only 50 percent (2+8) of the judgments favoring wetness when the temperature was high. Introspective notes taken at the time of the experiment indicate a definite cold cue for moisture "The cold ones always feel wet" is the subject's testimony.

Case No. 6 shows no definite evidence of a cue unless it is the ratio between the number of judgments favoring low temperature and those favoring high temperature. This ratio is a little over two to one (59 to 28) in favor of a cold cue. The notes say that the subject could tell the wet ones because they were colder.

Case No. 7 suggests a warm cue, 60 percent of the judgments favoring warmth in the *HL* combinations. The *LL-HH* combinations offer supporting evidence in that wetness is favored in only 50 percent (6+3+1) of the judgments when

the temperature is low whereas 85 percent (3+2+12) of the judgments favor wetness in one or both pools when the temperature is high. The subject says warm means wet; cold means dry.

In case No. 10 the evidence is entirely inconclusive. The subject evidently does not have a temperature cue for moisture. The notes say he "couldn't tell unless he moved his finger. Almost perfect when he moved his finger. Almost altogether guess work with fingers still." "I could feel the water soaking in," he says.

Case No. 11 is similar to No. 4; but the evidence is not quite so conclusive. Density seems to have been a supplementary cue. "I could tell that mercury was heavier than water."

Case No. 12 affords no conclusive evidence, though it seems to favor warmth as a cue. The subject said he didn't guess. "They just feel wet, that is all."

Cases No. 13 and 14 seem to be as inconclusive as No. 10. Cases No. 20 and 21 seem to favor a low temperature cue (64 percent and 59 percent) but corroborative evidence is lacking in the *LL-HH* combinations.

Cases No. 26 and 27 seem to favor a high temperature cue (68 percent and 54 percent). The evidence in the *LL–HH* combinations is inconclusive. However, the notes for No. 26 read: Question—"What makes you think it is wet?" Answer: "It was warm. You can feel water better when it's warm." For No. 27 the notes read: "The warm ones were wet because I could tell that they were lighter than the cold ones and water is lighter than mercury."

In case 28 the evidence is contradictory. The data seem to favor a cold cue (54 percent) supporting evidence from the *LL–HH* combinations but the notes say "Warm ones feel wet."

In case 29 we have a similar condition. The data seem to favor a low temperature cue (64 percent)without supporting evidence from the *LL–HH* combinations but the notes read—"I could tell that some of them were wet because they were warm."

The evidence in Case No. 30 is inconclusive. Apparently density was a moisture cue, for the subject says, "Sometimes they felt as if they were real thin; sometimes, real thick. I think the thin ones were generally the wet ones."

The data may be summarized by saying that in fifteen cases (1, 3, 5, 8, 9, 15, 16, 17, 18, 19, 22, 23, 24, 25, and 31) we have practically conclusive evidence of a definite temperature cue in the perception of moisture. In nine cases (2, 4, 6, 7, 11, 20, 21, 26, and 27) there is a reasonable presumption of a definite moisture cue. In five cases (10, 12, 13, 14, and 30) evidence is inconclusive; in two (28, 29) it is contradictory. In the 24 cases in which evidence indicates a definite temperature cue, or their is a reasonable presumption of such a cue, 19 favor a relatively cold temperature; 5 a warm temperature.

A study of the data shows further that there are probably other cues which are perceived as moisture. Among these is density.

Exploratory movements seem to be a great aid in the perception of moisture, as of course, they are in other perceptions. Several subjects testify that their judgments are largely guess work until exploratory movements are made.

A feeling of the 'creeping' of water along the finger may be a cue. This is capillary attraction and from a chemical standpoint, the essential characteristic of moisture. One subject says, "I could feel the water soaking in." Another says, "Along towards the last I could feel the water creeping up along my finger and in the dry ones there was just one line."

Evaporation plays an important part in the perception of moisture. Several subjects testify that they were able to check their responses immediately after the fingers were removed from the pools: "I could answer better after I had my fingers out." Another said he could always tell which was wet after he had removed his finger, and could tell when he was mistaken. "I think I am right when I have my fingers in there, but when I take my fingers out I can tell that I'm wrong when the air strikes my fingers."

We may summarize our conclusions as follows:

1. Temperature is a moisture cue in the case of many, but not all, individuals.

2. Moist is not necessarily "a blend of touch and cold." If it is a blend, then it frequently is a blend of touch and warmth as well.

3. The presumption is strong, though not scientifically demonstrated, that other cues such as density, capillary attraction, and evaporation, are often interpreted as concomitants of wetness.

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THE DURATION OF CUTANEOUS SENSATION (I) AND THE IMPROVEMENT OF ITS SENSIBLE DISCRIMINATION BY PRACTICE (II)

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I

The experiment consists of two parts. The part chosen for the two experiments is the same *i.e.* a small area—say *b*—of the left forearm about 50 mm from the wrist on its palmary side. An electro-magnetic pointer with an hair attached to its end was used for the experiment. It was then, through electric connection, attached to a metronome. So the rapidity of successive contacts was determined by the beats of the metronome and was gradually increased till they fused to an unitary sensation. By the application of this method it is observed that only two or three contacts in the sec. are felt as just separate, and so the duration of the sensation of moderate intensity varies from .5 to .3 sec. But when the intensity of the stimulus is greatly increased or it becomes rather painful the duration is much altered. Not only the sensitivity of the areas but also the intensity of the stimuli employed affects considerably the duration: At the tip of the finger the number of the separately felt contacts increases per second and so the duration decreases while the intensity of contact is moderately felt. The objective intensity of contact varies subjectively in different areas of the skin. As the felt intensity of the stimulas is greater, the lingering sensation continues longer and so the duration increases. The results of this experiment given by other observers are widely divergent.[1] The subjective difference of the intensity of contact may have caused greatly this varying result. The subject A observes that though the continuity of contact is quite clear, but still a vague feeling of succession seems to be mixed

[1] Külpe, Outlines of Psychology, p. 383.

in it. It appears that the stimulation spreads over to the neighbouring points in varying intensity and subsides therein earlier than in the point directly stimulated—thus causing the vague feeling of succession inter-mingling with the fusion. The wide divergence of results may also be due to the want of proper discrimination on this point.

II

The same area which was explored for the duration of the contact sensation was used to determine the improvement of its discriminative delicacy by practice. In making this experiment Spearmann's æsthesiometer was used. The experiment was each day taken twice almost at the same time with two subjects—one male and the other female, and was continued over a month. At each sitting thirty observations were made with each subject. The subject remained blindfold with the arm comfortably placed on a 'felt.' The æsthesiometer was applied to the skin uniformly and the distance between the points of contact was gradually increased or decreased as required for the method. In order to put off the effect of fatigue, too many observations at one sitting were carefully avoided by dividing the series into three parts—and allowing a pause of ten minutes after the completion of each part. The regularity of the interval of 3 seconds between the successive applications of the æsthesiometer was throughout maintained. The following table will show the space limen in mm of each subject.

There is practically no difference of discrimination which can be marked in the observations of the subjects in their morning and evening sittings. It is also difficult to say, on the basis of a single instance that the variability of space limen, as shown in the table, is greater for the woman than for the man. The table shows that the discriminative delicacy improves greatly in the third and the fourth weeks of the experiment. Now the question arises—whether this improvement is particularly peripheral or central; that is to say whether the improvement is only of the particular part exercised or it is an improvement of sensible discrimination of

I

Date	Subject I (Woman)		Subject II (Man)	
	M	E	M	E
November 3	20 mm	21 mm	14 mm	15 mm
November 4	16 mm	19 mm	16 mm	13 mm
November 5	12 mm	17 mm	15 mm	17 mm
November 6	20 mm	15 mm	15 mm	14 mm
November 7	10 mm	9 mm	12 mm	15 mm
November 8	9 mm	9 mm	13 mm	14 mm
November 9	9 mm	8 mm	13 mm	12 mm
Av. space limen 1st week	13.7 mm	14 mm	14 mm	14.2 mm
November 10	9 mm	9 mm	12 mm	10 mm
November 11	12 mm	10 mm	14 mm	15 mm
November 12	10 mm	9 mm	10 mm	9 mm
November 13	9 mm	8 mm	10 mm	10 mm
November 14	5 mm	9 mm	11 mm	9 mm
November 15	8 mm	8 mm	9 mm	10 mm
November 16	8 mm	6 mm	9 mm	9 mm
Av. sp. limen 2d week	8.7 mm	8.4 mm	10.7 mm	10.2 mm
November 17	5 mm	3 mm	8 mm	8 mm
November 18	3 mm	4 mm	6 mm	7 mm
November 19	4 mm	4 mm	5 mm	7 mm
November 20	3 mm	4 mm	6 mm	6 mm
November 21	4 mm	4 mm	5 mm	6 mm
November 22	3 mm	3 mm	4 mm	5 mm
November 23	3 mm	4 mm	6 mm	5 mm
Av. sp. limen or av. senst 3d week	3.5 mm	3.7 mm	5.5 mm	6.2 mm
November 24	3 mm	3 mm	5 mm	5 mm
November 25	3 mm	3 mm	5 mm	6 mm
November 26	4 mm	5 mm	6 mm	5 mm
November 27	3 mm	3 mm	5 mm	5 mm
November 38	4 mm	3 mm	7 mm	5 mm
November 29	3 mm	3 mm	4 mm	7 mm
November 30	2 mm	3 mm	5 mm	5 mm
Av. sp. limen 4th week	3 mm	3.2 mm	5.2 mm	5.4 mm

contact in general and so its effect is to be found also in distant parts of the skin. Wundt views "the difference in the structure of the sense organ is the chief cause of the different quality of the sensation. . . ." So all the qualitative differences which belong to any single organ have their necessary basis in the smaller variations, which may appear in the structure, or in the arrangement of the end organ. This view may not be much directly related to the question, but its indirect bearing on it is quite clear. It is a peripheral account of the local sign and suggests, on that basis an explanation of the improvement in which the local sign is also

involved. Dressler believes definitely that the improvement is local *i.e.* to the exercised part alone. But he admits he has not observed experimentally whether the sensibility is as a result raised outside.[2]

For proper investigation on this point the discriminative sensibility of three different points on each of the two forearms of each subject was, at the beginning recorded and then compared with the sensibility as afterwards found of the points after the completion of the experiment. The results are given in the table II for comparison.

II

Subject I	Left fore-arm			Right fore-arm		
	a	*b*	*c*	*d*	*b''*	*e*
Before practice	19	20	22	21	22	18
After practice	4	3.2	5	4	4	5.3
Subject II	*a*	*b*	*c*	*d*	*b''*	*e*
Before practice	16	14	12	16	15	15
After practice	7	5.2	8	9	7	6

b is the exercised part of the left forearm and *b''* its symmetrical part of the right forearm while *a*, *c*; and *d*, *e*; are the non-symmetrical parts taken on them. The table shows that the improvement is most in the exercised part but its effect is greatly noticeable also in other parts. It cannot here be said definitely that the symmetrical parts evince any greater effect of the improvement. After a week's interval the experiment was again made, but it was then found that the improved sensibility was greatly lost.

[2] Dressler, Psychology of touch, *Amer. J. Psych.*, 1893, p. 329.